Report No. CG-D-12-97

Phase I Feasibility Study: Seawater Hydraulic Transfer Pump

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Final Report
November 1996

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National Technical Information Service, Springfield, Virginia 22161

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Marine Safety and Environmental Protection, (G-M)
Washington, DC 20593-0001

and

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-12-97		

4. Title and Subtitle Phase I Feasibility Study: Seawater Hydraulic Transfer Pump	5. Report Date November 1996 6. Performing Organization Code Project Element No. 4120.3.1
7. Author(s) John Kunsemiller	8. Performing Organization Report No. R&DC 34/96
9. Performing Organization Name and Address Naval Facilities Engineering Service Center Port Hueneme, CA 93043-4328	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation United States Coast Guard Marine Safety and Environmental Protection (G-M) Washington, DC 20593-0001 U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6096	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code Commandant (G-MOR) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center technical point of contact is Kenneth Bitting, 860-441-2733.

16. Abstract

The Naval Facilities Engineering Service Center (NFESC) has completed a Phase I feasibility study to determine whether or not a seawater hydraulic design for the CCN-150 transfer pump system would reduce weight thereby making the system easier for U.S. Coast Guard (USCG) Strike Teams to deploy. The feasibility study included a review of commercially available seawater hydraulic system hardware applicable to this conversion and development of a seawater hydraulic transfer pump system design concept.

Based on results of the literature survey, concept development studies, and USCG National Strike Force operational requirements, it was determined that an open circuit seawater hydraulic system configuration of the transfer pump system with a lightweight hydraulic power source can provide a 3,000-pound savings over the present oil hydraulic system powered by the MOD 6 hydraulic power source. A secondary benefit of this seawater hydraulic system is improved system safety and environmental compliance through the elimination of hazardous hydraulic oil. These findings support NFESC's recommendation to proceed with a Phase II demonstration of a seawater hydraulic powered CCN-150 transfer pump.

It has also been determined that a reduction in transfer pump system weight and an improvement in pump performance can be achieved without conversion to seawater hydraulic operation. Replacing the present wire braided reinforced hydraulic hose with lighter weight thermoplastic hose can cut several hundred pounds off the system's weight. At the same time, using a 1-inch diameter supply, a larger 1.25-inch diameter return, and 0.5-inch diameter case drain hose sizes will alleviate flow restrictions and improve power source efficiency. This will allow use of the lighter Duetz power source for a significant weight savings over the now favored MOD 6 power source.

It became apparent during this investigation that other USCG hydraulic equipment such as skimmers and small pumps may be better candidates for conversion to seawater hydraulic operation. The application of seawater hydraulics to oil recovery type equipment may be more advantageous because these systems are typically operated closer to the water which would allow convenient access for seawater supply.

17. Key Words	18. Distribution Statement
oil spill equipment seawater hydraulics transfer pumps	This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. SECURITY CLASSIF. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

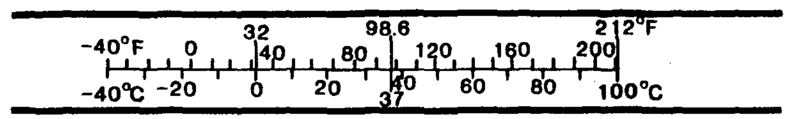
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares ($10{,}000\ m^2$)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

The Naval Facilities Engineering Service Center (NFESC) has completed a Phase I feasibility study to determine whether or not a seawater hydraulic design for the CCN-150 transfer pump system would reduce weight thereby making the system easier for U.S. Coast Guard (USCG) Strike Teams to deploy. The feasibility study included a review of commercially available seawater hydraulic system hardware applicable to this conversion and development of a seawater hydraulic transfer pump system design concept. Based on results of the literature survey, concept development studies, and USCG National Strike Force operational requirements, it was determined that an open circuit seawater hydraulic system configuration of the transfer pump system with a lightweight hydraulic power source can provide a 3,000-pound savings over the present oil hydraulic system powered by the MOD 6 hydraulic power source. A secondary benefit of this seawater hydraulic system is improved system safety and environmental compliance through the elimination of hazardous hydraulic oil. These findings support NFESC's recommendation to proceed with a Phase II demonstration of a seawater hydraulic powered CCN-150 transfer pump.

It has also been determined that a reduction in transfer pump system weight and an improvement in pump performance can be achieved without conversion to seawater hydraulic operation. Replacing the present wire braided reinforced hydraulic hose with lighter weight thermoplastic hose can cut several hundred pounds off the system's weight. At the same time, using a 1-inch diameter supply, a larger 1.25-inch diameter return, and 0.5-inch diameter case drain hose sizes will alleviate flow restrictions and improve power source efficiency. This will allow use of the lighter Duetz power source for a significant weight savings over the now favored MOD 6 power source. It became apparent during this investigation that other USCG hydraulic equipment such as skimmers and small pumps may be better candidates for conversion to seawater hydraulic operation. The application of seawater hydraulics to oil recovery type equipment may be more advantageous because these systems are typically operated closer to the water which would allow convenient access for seawater supply.

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INTRODUCTION

The U.S. Coast Guard's National Strike Force (NSF) uses portable hydraulic transfer pumps to provide emergency offloading capability to stranded tank vessels. A diesel power source supplies hydraulic fluid to drive the transfer pump. The use of oil as the hydraulic fluid for these transfer pump systems jeopardizes mission objectives. Hydraulic oil adds to system weight and increases logistics handling. Hydraulic oil leakage is an unnecessary risk, especially in environmentally sensitive areas. Most costly to achieving mission objectives are the resources and personnel required to transport the heavy transfer pump system.

The primary objective of this study was to determine whether or not a seawater hydraulic conversion of the oil hydraulic system would reduce system weight and make the CCN-150 transfer pump easier for U.S. Coast Guard Strike Teams to deploy. At the onset, it was projected that a seawater hydraulic design would reduce transportation weight and would improve system safety and environmental compliance through the elimination of hazardous hydraulic oil. As the study progressed, it became clear that optimization of the existing oil hydraulic system could achieve some reduction in system weight along with improved operational performance.

The results of our comprehensive investigation into the feasibility of reducing systems weight by application of seawater hydraulics to operate the transfer pump is documented in this report. A guiding philosophy for this effort was the application of available commercial technology. This Phase I report identifies the benefits and penalties for conversion of the transfer pump system for operation on seawater.

BACKGROUND

The Naval Facilities Engineering Service Center (NFESC) pioneered the development of seawater hydraulic tool systems and was the first to put into practice an operational diver tool system which used pressurized seawater as the working fluid. This seawater hydraulic diver tool system has demonstrated real benefits for using seawater hydraulics in environmentally sensitive areas (Ref 1). The diver tool system has shown that the corrosion issues and the requirements for close machine tolerances can be addressed using available technology.

Beyond any environmental reasons for adopting seawater hydraulics, a great advantage for using seawater hydraulics is the use of an open circuit design without a fluid return hose between the hydraulic pump and motor. For purposes of this report, the reader should understand that this non-return open circuit design is unique to seawater and water hydraulic systems. Unlike conventional open circuit designs were the fluid is returned to the power source reservoir,

the non-return open circuit design permits discharge of spent fluid at the work site. Figure 1 shows the conventional open circuit schematic in comparison with the non-return open circuit schematic.

A single transmission hose for the non-return open circuit is a great benefit to the operator in terms of weight and handling. It allows a longer distance between the prime mover and the work site because return line back pressure losses are eliminated. Because the fluid is not repeatedly cycled, there is little concern for heat build up, eliminating the necessity for hydraulic fluid cooling. The non-return open circuit system without these components can yield the greatest weight savings over conventional circuit design.

When comparing individual hydraulic components for seawater and oil systems, there is no inherent weight savings associated with the seawater hydraulic component. In fact, commercialization of oil hydraulic components generally provides a greater selection of lighter weight hydraulic components.

Seawater hydraulic technology for high pressure hydraulic systems is relatively new technology. Table 1 presents a summary of available seawater hydraulic components for several candidate systems. The table also highlights areas where some effort in technology development is necessary to achieve the capability. While not inclusive of all manufactures, the table is intended to show basic capabilities and areas of deficiency.

In addition to the NFESC effort to reduce transfer pump system weight through application of seawater hydraulic system design, the Carderock Detachment of the Naval Surface Weapons Center (CDNSWC) at Annapolis, Maryland is conducting a separate investigation into the use of composites for select transfer pump components as a means to reduce pump weight (Ref 2). The weight savings associated with the seawater hydraulic system design is intended to compliment the accomplishments of CDNSWC. Application of composite technology to specific seawater hydraulic components may be appropriate to augment any systems weight savings.

Component Description

The submersible CCN-150 transfer pump shown in Figure 2 is part of the Navy and Coast Guard petroleum, oils and lubricants transfer (POL) system (Ref 3). The CCN-150 is a single stage centrifugal pump designed for high pumping efficiency and prolonged immersion in seawater and petroleum products. The pump used by the Coast Guard is substantially the same as the pump held in the Emergency Ship Salvage Material (ESSM) equipment pool maintained by the Navy. For this report, a generic CCN-150 designation will be used unless a specific reference to model number is required. Table 2 summarizes the component weight of the transfer pump equipment.

The Navy issue CCN-150-1C Thune Eureka and the CCN-150-3C Kvaerner Eureka are limited to 2,370 psig and 52 gpm of hydraulic supply as measured at the pump hydraulic inlet, or 2,500 psig and 52 gpm of hydraulic supply as measured by the hydraulic prime mover gauges. Because of shaft seal failure at the motor/impeller interface, these units should not exceed 200 psig of back pressure as measured at the pump hydraulic outlet. The pump is reported to weigh 279 pounds (Ref 2).

The Coast Guard has a newer CCN-150-5C Kvaerner Eureka pump which most notably differs in flow rate from the -1C and -3C models. Data obtained from the USCG provides CCN-150-5C pump curves for flow rates up to 79 gpm. Review of the specifications for the

	Hydraulic Hand Tools	Manipulator System	Vehicle Propulsion System	Transfer Pump	Vehicle Ballast System	Deep Ocean Work System
Pumps	Topside Fixed Displacement Piston 5 - 20 hp (Cat, Harben) Submersible Fixed Displacement Piston 5-15 hp (Fenner, Danfoss)	Submersible Fixed Displacement Vane 0.5 - 2 hp (NFESC) Submersible Fixed Displacement Piston 2-5 hp (Fenner, Danfoss)	Submersible Fixed Displacement Piston 2-5 hp (Fenner, Danfoss) **Need:** Submersible Variable Displacement Piston 15 hp (NFESC mod to DELPUMP)	Topside Fixed Displacement Piston 40-80 hp (Hauhinco, Fenner, Danfoss)	Submersible Fixed Displacement Vane 0.5 - 2 hp (NFESC)	Submersible Fixed Displacement Vane 0.5 - 2 hp (NFESC) Submersible Fixed Displacement Piston 2-7 hp (Fenner, Danfoss)
Motors	Submersible Fixed Displacement Vane 2 - 3 hp (NFESC) Submersible Fixed Displacement Piston 2 - 5 hp (Fenner, Danfoss)		Submersible Fixed Displacement Piston 2 - 5 hp (Fenner)	Submersible Fixed Displacement Piston 60 hp (Fenner)		Submersible Fixed Displacement Vane 2 - 3 hp (NFESC) Submersible Fixed Displacement Piston 2 - 5 hp (Fenner)
Valves (various vendors)	Manual Control 2-Way, 2-Position 3-Way, 2-Position Pressure Compensated Flow Control	**Need:** Submersible Servo Control 0.5-5 gpm @ 2000 psi	Submersible Solenoid Control 2-Way, 2-Position 3-Way, 2-Position	Manual Control 2-Way, 2-Position 3-Way, 2-Position	Submersible Solenoid Control 2-Way, 2-Position 3-Way, 2-Position	Submersible Solenoid Control 2-Way, 2-Position 3-Way, 2-Position Pressure Compensated Flow Control **Need:** Submersible Servo Control 0.5-5 gpm @ 2000 psi
Actuators (various vendors)	Linear Rotary	Linear Rotary				Linear Rotary
Fluid Conditioning (various vendors)	Low Pressure Filters 10 - 60 micron	High Pressure Filters 10 micron	High Pressure Filters 10 - 50 micron	Low Pressure Filters 10 - 60 micron Heat Exchangers	Low Pressure Filters 10 - 60 micron	High Pressure Filters 10 - 50 micron
Auxiliary Components (various vendors)	Gauges Meters	Gauges Meters Linear/Rotary Encoders	Gauges Meters	Gauges Meters	Gauges Meters	Gauges Meters Linear/Rotary Encoders

Table 1. Capability Summary for Seawater Hydraulic Components for Several Systems

Rexroth model A2FM-80 motor that drives the pump shows 71 gpm as maximum flow rate at a maximum pressure of 5,500 psi. Whereas the -1C and -3C pumps are plumbed for only a supply and a return line, the -5C also is plumbed for a case drain line. The case drain line is necessary to prevent shaft seal blowout.

Table 2. Summary of CCN-150 Transfer Pump System Weight

Component	Weight (lbs)
CCN-150-5C	196
Precharged Supply, Return & Drain Hydraulic Hoses (200 feet each)	615
Hydraulic Oil (40 gallons reserve)	280
MOD 6 Power Source with Fluids	4,100
TOTAL	5,191

The CCN-150-5C is constructed from stainless steel for pumping chemicals in addition to seawater and petroleum products. The pump is driven by an internal hydraulic motor directly connected to the motor shaft. The pump shaft is supported by a heavy duty ball bearing at the motor end. This bearing is lubricated and cooled by case drain oil from the hydraulic motor. A carbon-impregnated bushing supports the pump shaft at the lower end for -1C and -3C models. The carbon-impregnated bushing is lubricated and cooled by immersion in the pumped fluid.

Requirements

The following requirements for transfer pump system operation and performance were provided by the Coast Guard as guidance for this feasibility study.

- Maintain equivalent transfer pump performance.
- Use seawater hydraulic system design to reduce system weight.

Other, more specific requirements were developed in conjunction with the Coast Guard.

- CCN-150 external dimensions cannot exceed 12.5 inches in diameter (maximum size of a Butterworth opening through which the transfer pump must pass).
- All transfer pump system components must be helicopter transportable.
- Because of the potential for operation in explosive environments, electric powered equipment is unacceptable, including the starting system for the diesel engine on the power source.
- The stranded vessel is unable to provide power or water requirements, therefore, the transfer pump system must be self sufficient.

An in-kind replacement of the Rexroth hydraulic motor is desired. The hydraulic motor must be capable of submerged operation since the motor is in direct contact with the pumped fluid. The motor should fit within the available space so as not to interfere with the pumped fluid flow. Specific performance requirements for the transfer pump were developed through review of the CCN-150 hydraulic motor specification (CCN-150-5C uses a Rexroth A2FM-80 series motor) and of the operation manuals. Figure 3 provides curves for CCN-150 performance for pumping water and for pumping oil.

FINDINGS

The investigation into a seawater hydraulic conversion for the CCN-150 included a literature survey, concept development studies, and conversations with USCG Pacific Strike Team (PST) members to determine system operational data. In addition to demonstrating the operation of the CCN-150 transfer pump system, the PST also provided a CCN-150-1C pump for familiarization and as a platform for future laboratory testing. The following sections describe the results of our study on the CCN-150 transfer pump system. A listing of citations for the literature survey can be found in Appendix A.

Motor Replacement

One of the first areas investigated was availability of a suitable seawater hydraulic motor to replace the Rexroth motor. Because input torque curves were not available for the CCN-150 pump impeller, the Rexroth motor output specifications were used to select candidate motors. Our literature searches and Commerce Business Daily sources sought announcements identified two potential vendors: Fenner Water Hydraulics and Danfoss Fluid Power. Both manufacture's specialize in freshwater hydraulic system components. Copies of the Fenner and Danfoss literature can be found in Appendices B and C, respectively. A listing of the responses to the sources sought announcement is included as Appendix D.

Table 3 presents a comparison of closest available hardware from each vendor against the Rexroth motor specification. Though capable of operation up to 5,800 psi input pressure, Table 3 specifications on the Rexroth motor were limited to 2,370 psi for this comparison for two reasons. First, 2,370 psi is the reported (Ref 4) pressure limit for operation of the CCN-150-1C and -3C transfer pumps. The second reason to limit the comparison to 2,370 psi is that the available USCG power sources are unable to provide higher pressure at the supply flow rate.

Danfoss does not have a motor of the required size range for this application. The Danfoss MAH 12.5 unit is the largest motor offered at just over 11 horsepower. NFESC contacted Danfoss representatives in the U.S. and in the U.K.. Danfoss was willing to undertake a development effort for a large motor but they were not offering their larger size pump for conversion to a motor. There is no obvious reason why the larger Danfoss PAH 80 piston pump could not be used as a motor. Danfoss may be unwilling to risk company reputation without prior investigation. Because the objective is to select off-the-shelf equipment, the Danfoss motor was not investigated further.

The standard Fenner F60 motor for freshwater operation is available for purchase for under $10,000. Some material changes are required for sustained operation on seawater which naturally raises the price. NFESC has had satisfactory experience with a nominal 7 horsepower Fenner F15 motor modified for seawater operation (Figure 4). Although the F60 unit is underpowered for this application, it is reported to produce 70 horsepower when operated at 3,000 rpm. The technology is easily scaled up to a motor that can equal the Rexroth performance with little risk.

Table 3. Comparison of Rexroth, Fenner, and Danfoss Hydraulic Motor Specifications

Specifications:		Rexroth Motor (Oil)	Fenner Water Hydraulics	Danfoss Fluid Power (Water)
Displacement	$in.^3/rev$	4.90	3.80	0.75
Max. Speed	rpm	3,350	(3,000)	3,000
Flow Rate	gpm	71	(58)	11
Pressure	psi	2,370*	2,030	2,030
Torque	in.-lb	1,566 @ p=2,030 psi 1,804 @ p=2,370 psi	1,159 @ p=2,030 psi	234 @ p=2,030 psi
Diameter	in.	5.5	5.5*	3.6*
Length	in.	10.2	9.5	8.0
Weight	lb	51	40 - Aluminum Body 49 - S.S. Body **	8.6 - Special Coated Aluminum
Power	hp	85 @ p=2,030 psi 98 @ p=2,370 psi	(69.6 @ p=2,030 psi)	11.1 @ p=2,030 psi
Comments		Based on A2FM -80/61L Specs. * CCN-150-1C and power source limit. Motor rated to 5,800 psi.	Based on F60 Specs. Numbers in parenthesis refer to FAX from Simon Usher dated 10/15/93. * Not including flange. ** Brochure erroneously lists 97 lb.	Based on type MAH 12.5 which is largest available motor size. * Not including flange.

The Fenner brochure incorrectly reports a F60 weight of 97 pounds (44 kg). The correct weight for the F60 in stainless steel is 49 pounds (22 kg), just less than the Rexroth motor weight of 51 pounds (23 kg). Further weight reduction of the Fenner motor may be attained through use of composites for the housing sections. Initial conversations with Mr. G. Wilhelmi at CDNSWC indicate that the housing for the Fenner design is an ideal application for composites because it essentially is comprised of two flat plates and a cylinder that are held together with tie rods. The housing is much less complicated than the internal piston rotating group. A composite housing would be low risk and a cost effective reduction in component weight.

Hydraulic Flow Restrictions

As with any hydraulic system, a significant reduction in performance results from return flow fluid frictional losses. This is problematic in the current transfer pump system because the Coast Guard needs the ability to add hose length to the system in order to extend operating distance from the power source. As the 50-foot sections of hydraulic hose are added using quick disconnect hose couplings, system efficiency decreases. The quick disconnects, small hose size, and extended lengths contribute to the total flow restriction.

The CCN-150-5C transfer pump operations manual specifies a 1-inch-diameter supply and a 1.5-inch-diameter return hose to pass a maximum 79-gpm flow rate. The Naval Sea Systems Command (NAVSEA) Technical Manual (Ref 4), applicable to the -1C and -3C transfer pumps, specifies a 1-inch-diameter hose size for both supply and return hose. These early model pumps are limited to a 52-gpm flow rate. The PST uses a 1-inch-internal diameter supply and return hose size. A 1/2-inch-diameter case drain line is used with the -5C pump.

The following example illustrates the significance of these frictional losses in the Coast Guard system. Table 4 shows a 1.19-psi/foot drop in pressure at a 50-gpm flow rate through a 1-inch-diameter hose or a 238-psi drop over a 200-foot hose length. Add to this a 20-psi drop for each of five quick disconnects used to join the 50-foot hose sections and the total pressure drop is over 300 psi. This is 100 psi in excess of the maximum 200-psi return line back pressure specified in the NAVSEA technical manual. At 50 gpm, this pressure drop equates to more than an 8 horsepower loss in system power. This energy waste goes directly into heating the fluid, causing a loss in fluid viscosity. As the hydraulic fluid thins, the volumetric efficiency of the prime mover pump and the CCN-150 internal motor decrease due to internal leakage. The result is an overall loss in pump system performance.

A larger diameter return line will improve transfer pump performance for the current hydraulic system and will be required to operate at the full 79-gpm flow rate capacity of the CCN-150-5C. Table 4 shows that a 1.25-inch-diameter hose at 50 gpm results in a 78-psi pressure drop over a 200-foot hose length. Even after adding the 100-psi pressure loss associated with the five quick disconnects, the larger hose diameter provides a significant improvement. At a 70-gpm flow rate, the 1.25-inch-diameter hose produces a total of 252-psi drop over a 200-foot hose length including quick disconnects. At 70 gpm, the 1.5-inch hose results in a total of 162-psi pressure drop for the same hose condition.

An advantage for the seawater hydraulic system is that smaller diameter hoses for equivalent flow rates can be used because of the lower viscosity of seawater. The seawater prime mover pump and seawater motor are designed for low viscosity seawater operation. Table 5 shows that a seawater flow rate of 50 gpm through a 1-inch-diameter hose results in a 136-psi pressure drop over a 200-foot hose length. This is an acceptable drop in pressure and the small hose size can achieve desired weight savings and flexible handling characteristics.

Table 4. Fluid Flow Velocity and Pressure Drop for Hydraulic Oil

Flow Rate (gpm)	**Hose Diameter (in.)**	**Pressure Drop (psi/ft)**
30	1.00	0.43
	1.25	0.14
	1.50	0.06
40	1.00	0.76
	1.25	0.25
	1.50	0.10
50	1.00	1.19
	1.25	0.39
	1.50	0.16
60	1.00	1.71
	1.25	0.56
	1.50	0.13
70	1.00	2.33
	1.25	0.76
	1.50	0.31

Table 5. Fluid Pressure Drop for Seawater Versus Hydraulic Oil for a 1-inch-diameter Hose

Flow Rate (gpm)	**Seawater Pressure Drop (psi/ft)**	**Hydraulic Oil Pressure Drop (psi/ft)**
30	0.24	0.43
40	0.43	0.76
50	0.68	1.19
60	0.97	1.71
70	1.32	2.33

Hose Selection

Table 6 provides a comparison of select thermoplastic hose against the wire-reinforced hose currently in use by the PST. Thermoplastic hose provides a weight savings of as much as 75 percent over wire-reinforced rubber hose. The Aeroquip FC324-16 hose used on the transfer pump system is rated to 4,000-psi working pressure and weighs 1.22 pounds per foot. It should be noted that the 4,000-psi working pressure of the FC324-16 hose is 33 percent greater than the pressure capability of the USCG designed Duetz power source. This hose however, appears to be the best rated in terms of weight per foot. See Appendix E for a complete listing of the hoses included in this study.

Aeroquip stocks a thermoplastic 1.25-inch-diameter hose (p/n FC701-20) that is rated to 2,500 psi working pressure and weighs 0.58 pounds per foot. The 12-inch bend radius is equivalent to the bend radius for the current FC324-16 hose. Using this hose on the return side for the transfer pump would provide dual benefit. There would be a 32 percent reduction in precharged hose weight over the FC324-16 hose (a 95-pound savings on a 200-foot return including the weight of the oil). Additionally, the hydraulic flow restriction would be minimized.

Parker Hannifin offers a special order 1.5-inch-diameter thermoplastic hose (p/n 573X-24) rated to 3,000 psi working pressure. This hose has a 18-inch minimum bend radius and a weight of 0.81 pounds per foot. This hose would satisfy future requirements for oil flow rates through 79 gpm. A 200-foot precharged length of this hose would still retain a 3 percent reduction in hose weight over the FC324-16 hose (a 10-pound savings for a 200-foot hose section including the weight of the oil).

Table 6. Comparison of 1-inch-diameter Thermoplastic Hydraulic Hose Against Currently Used Wire-braided Hose

Hose Description	**Working Pressure (psi)**	**Bend Radius (in.)**	**Weight Per Foot (lb)**
Aeroquip FC324-16 (Wire Braided)	***4,000***	***12***	***1.22***
Parker 593-16 (Thermoplastic)	3,250	8	0.68
Furon Synflex 3350/3360-16 (Thermoplastic)	3,000	8	0.42
Parker 573X-16 (Thermoplastic)	3,000	10	0.41
Aeroquip FC702-16 (Thermoplastic)	3,000	12	0.36
Aeroquip FC701-16 (Thermoplastic)	2,500	12	0.36
Parker HPSH-16 (Thermoplastic)	2,500	4	0.35

For a seawater system, the lower viscosity of seawater allows use of smaller diameter hose when compared to equivalent oil flow rates. Use of 1-inch-diameter thermoplastic hose rated to 3,000 psi working pressure would provide acceptable performance for a seawater

hydraulic transfer pump system. Furon Synflex 3350/3360-16 thermoplastic hose can meet this working pressure and it weighs 0.42 pounds per foot with a minimum bend radius of 8 inches.

This hose is recommended over the slightly lighter Aeroquip FC702-16 hose because of its flexibility and the polyurethane jacket. Though possible not as robust as rubber jacketed wire-braided hose, the polyurethane jacketed thermoplastic hose should provide suitable protection from abrasion caused by deck handling. Use of the Synflex hose with a seawater hydraulic system will provide a 65 percent reduction in hose weight (a 320-pound savings for 200 feet each of supply and return) over the current oil hydraulic system.

Power Source Conversion

Light weight is a primary factor although the power sources are not required to be man portable. Two power sources have been used by the Coast Guard with more or less success to operate the CCN-150 transfer pump. Table 7 is a comparison of the specifications for the Navy MOD 6 and the Coast Guard power sources. Each unit can supply a typical flow rate of 52 gpm at 2,500 psi. This is well off the maximum 79 gpm at 5,000 psi capability of the CCN-150-5C but is at the best performance specification for the CCN-150-1C.

Table 7. Comparison of Navy MOD6 and Coast Guard Hydraulic Power Source Specifications

Power Source	Weight (lb)	Dimensions (in.)	Flow Rate Capability
Navy MOD 6	4,100	98 x 34 x 58	52 gpm at 2500 psi
Coast Guard Duetz	1,735	68 x 40 x 48	50 gpm at 3000 psi

The NAVSEA MOD 6 power source, part of the Coast Guard Viscous Oil Pump System (VOPS), is used by the PST for CCN-150-5C operation. This skid-mounted power source is powered by a two stroke diesel with a twin vane pump. Each pump section is capable of an independent 26-gpm flow rate. Operation of the CCN-150 requires combining the two outputs to supply 52 gpm at 2,500 psi. The addition of a case drain return fitting to the reservoir was required to accommodate the CCN-150-5C. Because of weight, the MOD 6 power source is not considered a good candidate to base a seawater conversion. Figure 5 is a photo of a MOD 6 power source used by the PST.

PST members report the MOD 6 power source is more capable of maintaining performance for extended duration because of the two stroke diesel design. Our investigation suggests that the sustained performance is the result of lower frictional losses. The output of the twin vane pump is supplied to the CCN-150 via dual 1-inch-diameter supply and return hoses. The flow is combined at the pump using a custom manifold (Figure 6). The dual hose has the effect of reducing flow restrictions and would be equivalent to using a single 1.4-inch-diameter hose. Obviously, the benefit is a significantly reduced pressure drop afforded by the larger flow area leading to less heating and viscosity loss in the hydraulic fluid.

The USCG lightweight power source is powered by a Duetz four stroke diesel engine. This skid-mounted power source includes a variable displacement piston pump that provides 50

gpm at 3,000 psi maximum pressure. Reports by PST members that this power source is unable to maintain extended performance are attributed to the flow restriction and viscosity loss discussed earlier in this report. Conversion of this power source or development of a power source around the Duetz engine is a viable alternative for future seawater operation.

Because of the potential for operation in an explosive atmosphere, the Coast Guard uses a hydraulic starter to start the diesel engines on the MOD 6 and Duetz power sources. Ether is used in cold climates to assist in diesel start because of the absence of glow plugs. The hydraulic starter consists of a hand pump that draws fluid from the hydraulic system oil reservoir to pressurize an accumulator. Release of the accumulator charge drives a small hydraulic motor to rotate the engine for starting. Figure 7 shows the hydraulic starter motor and associated accumulator on the Duetz power source.

Conversion of this starting system to a seawater hydraulic system appears to be within the available technology. Selection of one of the smaller Fenner motors may be adequate for such a conversion, however, a specific starter design was not addressed in this study. Maintaining the existing oil hydraulic starter system is recommended at this point in the project. This would require a small (approximately 1 gallon) oil resevoir to operate the starter.

Selection of a Prime Mover Pump

Ancillary equipment such as filters, hoses, and valves are available from many commercial sources, however, the selection of a prime mover seawater pump, like the seawater motor, is limited to a few manufacturers. Table 8 presents the products of several pump manufacturers identified in the literature search.

Table 8. Summary of Candidate Prime Mover Pumps

Manufacturer/Model	**Type**	**Capacity**	**Weight** (lb)
Aqua-Dyne/GA Series	Triplex Plunger	60 gpm @ 550 rpm 2,400 psi @ 100 hp	1,400
Giant/Series XP 15,000	Triplex Plunger	55 gpm @435 rpm 2,600 psi @ 100 hp	750
Hydrowatt/R130S	Radial Piston	52 gpm @ 1500 rpm 4600 psi @136 hp	507
Hauhinco/RKP-160	Radial Piston	62 gpm @ 1500 rpm 2,900 psi @ 100 hp	485
Fenner/F120	Axial Piston	48 gpm @ 1500 rpm 2,030 psi @ 60 hp	99
Danfoss/PAH 80	Axial Piston	29 gpm @ 1500 rpm 2,320 psi @ 44 hp	81
FMC */Series C52.0	Axial Piston	52 gpm @ 1750 rpm 1,000 psi @ 32 hp	65

* Previously manufactured under the trade name Delpump by CHPT Incorporated.

The Giant, Aqua-Dyne, and Hydrowatt pump designs are old technology in that they rely on oil lubrication at critical wear interfaces. These triplex plunger and radial piston designs pay a significant weight penalty for the use of an intermediate oil lubricated pump section which must be sealed from the water section of the pump. The size and weight make these pumps unacceptable for USCG application.

The three axial piston type pumps shown in Table 8 represent new technology for high pressure pumping of water in that they are totally water lubricated. Each of these units is designed for water as the hydraulic fluid and lubricant. The Danfoss PAH 80 is the smallest unit and would not be able to meet the flow requirements to operate the transfer pump. Combining the flow output from twin PAH 80 units, similar to the MOD 6 power source twin vane pump arrangement, is one approach to meeting the flow requirements. This arrangement would also provide some backup capacity in the event of a single pump failure. Likely a gearbox arrangement would be required to split the diesel output to each pump. The addition of a gearbox however, would be additional weight.

The FMC Series C52.0 is a lightweight composite pump previously marketed as Delpump by CHPT. At 65 pounds, the C52.0 has the lowest weight of the available pumps. The singular drawback of this pump is the low output pressure of 1,000 psi. The principal market for this design is reverse osmosis units and not the demands of a hydraulic system. NFESC experience with this design has shown that the upper limit for pressure output is around 1,500 psi. Because of this limitation, the FMC pump would not meet USCG requirements.

The Fenner F120 pump best fills the need for a prime mover pump even though it is underrated. The flow rate for this pump may be increased to the 60 gpm needed to operate the F60 size motor by operating at a faster shaft speed. The F120 pump provides a compact design capable of high pressure operation to 2,030 psi. The literature reported weight of the F120 pump is out of date. Fenner now reports a weight of 99 pounds for the F120 pump. Like the motor, the use of composites for the housing could lead to an important reduction in unit weight.

Other Hydraulic Equipment

The Strike Teams have a host of portable hydraulic equipment, most of which use the two previously reported hydraulic power sources. A third power source on inventory at the PST is referred to as the AVCO Type 3 (Figure 7). This 70 horsepower power source is primarily used for the Open Water Oil Containment Recovery System and requires a separate oil cooler unit to dissipate waste hydraulic oil heat. Other equipment supported by this power source can be characterized as having a small hydraulic demand in comparison to the CCN-150 pump. The various oil recovery type equipment listed below requires from 3 to 25 gpm at 2,500 psi:

- Vessel of Opportunity Skimmer System (VOSS)
- Viscous Oil Pump System (VOPS)
- Retrieval Rack
- Inflatable Boom Blower
- Pump Float Skimmer
- Archimedes Screw

The nature of operation from small boats or barges makes this equipment ideal for operation on seawater hydraulics. Many of the advantages for an open circuit hydraulic system can be realized for these systems. Specific investigation of seawater hydraulic conversions of this equipment, however, was beyond the scope of this work.

SYSTEM CONCEPTS

Two circuit design configurations were reviewed for a seawater hydraulic powered transfer pump system. A non-return, open circuit system, like that used in the Navy diver tool system, potentially offers the best reduction in systems weight. The basic disadvantage of the non-return open circuit design is that it must be located next to an adequate water supply. A conventional open circuit system design, like the current oil system design, has the advantage of operating from any suitable location without the need for a continuous water supply. The disadvantage of the conventional open circuit system design is that it offers limited opportunity for any weight savings because components such as coolers and return hoses are all required. A comparison of the two system concepts resulted in the selection of a conventional open circuit system design as best meeting USCG operating requirements and project objectives.

Table 9 presents a pro/con comparison of the open circuit seawater system design. It is evident that despite several good reasons supporting the open circuit design, the difficulty in obtaining a ready supply of seawater makes an open circuit design undesirable for the transfer pump system. USCG requirements assume that the host ship is "dead" in the water and cannot provide a water supply off the fire main for example. Therefore, operation over the side of a large tanker vessel where the ocean water may be as much as 100 feet below the deck requires some form of lift pump.

Weight of equipment required to supply seawater to an open circuit power source would negate any weight saved from the single transmission hose. Possible arrangements include adding an air compressor to the power source to operate a pneumatic pump or using some of the available internal combustion or electric driven pumps. As an example, National Mastr Pump (Houston, Texas) offers a self-priming hose pump that can deliver 66 gpm at a total dynamic head maximum of 96 feet. The gasoline powered model MG5 weighs 110 pounds plus fuel and hose. The drawback of this unit is that it would have to be suspended over the side of the ship and would significantly outweigh the 84-pound savings associated with elimination of the hydraulic return hose.

Table 9. Advantages and Disadvantages of a Non-return Open Circuit Seawater Design

Pro	Con
Single transmission hose for reduced weight and easier handling	Additional equipment required to lift intake water from ocean to power source
No hydraulic fluid transportation weight	
No oil cooler required	
High pressure washer could be added	

Alternatively, an open circuit conversion option on a closed circuit system design may provide system flexibility for those cases where an adequate supply of water can be provided by the host ship. The decision on whether to mobilize as a closed or open circuit system could be made based on the incident report prior to departing on the mission.

A conventional open circuit for a seawater hydraulic system offers greater flexibility for site selection and does not add lift pump hardware to the equipment list. Table 10 presents the component weight of a conventional open circuit seawater hydraulic transfer pump system and the expected weight savings.

Table 10. Summary of Seawater Hydraulic CCN-150 Transfer Pump System Weight Savings

Component	Weight (lb)	Savings (lb)
CCN-150	196	No Change
Thermoplastic Supply, Return & Drain Hydraulic Hoses (200 feet)	195	420
Hydraulic Fluid *	0	280
Seawater Power Source	1,800	2,300 **
TOTAL	2,191	3,000

* Assumes capability for one time fill is available on site.
** Based on MOD 6 power source.

Overall transportation weights are reduced by elimination of hydraulic oil, provided there is a method on site for a one time fill (about 60 gallons) of the hydraulic system (plus any required make up water). The fire mains or other ship pumps might serve to fill the transfer pump system. If water is not available on site, carrying it along adds another 500 pounds to system transportation weight.

The weight savings primarily comes from use of thermoplastic hose and a lighter power source. Parts of both of these weight savings are applicable to present oil hydraulic systems. The benefit of thermoplastic hose has been discussed previously. The USCG is already preparing to take advantage of the lighter weight Duetz power source as a replacement for the MOD 6 power source.

Issues

Unique to seawater hydraulic component design and system operation are the issues of bearing design and extreme temperature. Probably the most frequently raised issue is the operating range of seawater. Care must be exercised to maintain the water above freezing or internal damage to the hydraulic components can result. The second issue is associated with development of water lubricated technology to support component designs requiring ball bearings. Because seawater does not provide a good lubricating film, all water lubricated component shaft bearings must now be supported by polymer sleeves rather than conventional

ball or roller bearing design. Careful design and operation can minimize the effect of these issues on the seawater hydraulic system performance.

Temperature. The freezing temperature of seawater falls within the desired transfer pump operating envelope of 0°F to 140°F. A frozen seawater hydraulic system must be thawed prior to use. Once a seawater system is operating, waste heat keeps the seawater from refreezing. This is particularly true for a conventional open loop circuit where recycling keeps the fluid temperature above freezing. If the situation warrants, an environmentally friendly glycol additive could be used in the system to lower the freezing point.

In comparison to oil, water has a narrow viscosity range making it an ideal fluid for a hydraulic system. While the kinematic viscosity of a general purpose hydraulic oil (MIL-H-5606) may undergo a 35 to 40 centistokes decrease over a 100°F increase in temperature, water undergoes less than a 2 centistokes change. Because water does not thin out like hydraulic oil as it gets hotter, water hydraulic components tend not to suffer from increased internal leakage leading to reduced volumetric efficiency.

Manufacturers of oil hydraulic equipment recommend a fluid operating temperature range of 40°F to 140°F. Below 40°F, the oil must be heated and gradually circulated to prevent system damage. Hydraulic fluid additives help ensure (within this temperature envelope) that the oil viscosity will not be too thick for cold weather startup or too thin for warm weather operation. As temperature increases, these additives break down and the hydraulic fluid looses its desired properties.

Between the extremes of freezing and boiling, seawater provides a much larger temperature range from about 40°F to 180°F. Within this range, viscosity is relatively constant and there is no need for additives. A conventional open circuit seawater hydraulic system will require a hydraulic fluid radiator to transfer the excess heat to the atmosphere. Construction of the heat exchanger will require corrosion immune material because of the corrosive nature of seawater.

Pump Bearing Design. The CCN-150 pump shaft is supported by a heavy duty ball bearing at the motor end (Figure 9). This ball bearing is lubricated and cooled by case drain oil from the hydraulic motor. Because of the large axial and lateral loads carried by this bearing, the use of a polymer bushing for water lubrication may not be feasible. Such a bushing design would require a larger shaft diameter and additional bearing length in order to establish hydrodynamic support. As a result, the transfer pump may be larger and heavier.

A carbon impregnated bushing supports the pump shaft at the lower end for -1C and -3C models. The carbon impregnated bushing is lubricated and cooled by the fluid being pumped. Damage to this bearing (Figure 10) suggests that either the unit was run dry or was otherwise damaged during operation or maintenance. This damage is a good reminder of how delicate bushings can be. In the CCN-150-5C, this bushing has been removed and the impeller load is supported completely by the bearing at the motor end.

In this case, the bearing at the motor end should be sealed from the pumped fluid and seawater hydraulic system, and lubricated with oil. Maintaining this sealed oil chamber for bearing lubrication would be a minor addition to the maintenance procedure. Pressure compensation of this oil cavity would not be necessary due to the limited depths that the transfer pump is submerged.

CONCLUSIONS

The following conclusions have been drawn as a result of this investigation into the application of seawater hydraulics for the purpose of reducing the CCN-150 transfer pump system weight:

1. Conversion of the CCN-150 transfer pump for seawater hydraulic system operation is feasible using commercially available technology. Replacement of the existing oil hydraulic motor with an appropriately sized seawater compatible motor will provide existing transfer pump performance with no weight penalty.

2. A non-return open circuit hydraulic system design is not the best choice for the CCN-150 transfer pump system because USCG requirements assume that the stricken tank vessel is "dead" in the water and unable to supply the seawater demand. Addition of a separate lift pump to supply the transfer pump system with seawater negates any weight savings associated with the open circuit design.

3. Given the desired operation scenario, a conventional open circuit hydraulic system design provides greater flexibility for on-site location and easier equipment support. As much as 3,000 pounds can be saved from the present CCN-150 transfer pump system weight by converting to seawater hydraulics and by using thermoplastic hose.

4. Freezing temperatures can cause equipment damage and system failures if the seawater hydraulic system is not adequately warmed prior to operation. A open circuit hydraulic system design can minimize the effect of operation in a cold climate because the seawater should naturally warm as it is recirculated. In addition, the use of an antifreeze additive is an option in a closed circuit system.

5. A power source option to convert from a conventional to a non-return open circuit configuration may provide additional system flexibility for situations where a continuous supply of water can be provided by the host ship. The non-return open circuit design could then provide additional weight savings through removal of the hydraulic return hose.

6. The elimination of hydraulic oil will benefit the USCG by reducing system weight and the environmental hazards associated with oil hydraulic system operation. Much of this benefit will be realized during month-to-month equipment maintenance and ready load preparation at the home port.

7. A 370-pound weight savings can be achieved with the present oil hydraulic transfer pump system if thermoplastic hose is used instead of the wire braided reinforced rubber hose (based on 1-inch-diameter supply/return and 0.5-inch-diameter case drain hose sizes).

8. Review of the CCN-150 operating parameters showed that the present 1-inch-diameter hydraulic return hose is too restrictive for a 52-gpm oil flow rate. A significant improvement in the CCN-150 and Duetz power source performances would be achieved by using a 1.25-inch-diameter hose. Any weight penalty associated with the larger diameter hose can be reduced by using thermoplastic hose.

9. The NSF has hydraulic powered oil recovery and cleanup equipment that is smaller in horsepower than the CCN-150 transfer pump system. The use of this equipment from small vessels or on land makes these systems better candidates for seawater hydraulic operation. The application of the open circuit seawater hydraulic system design may be advantageous for this equipment.

RECOMMENDATIONS

The following recommendations are presented based on the results and conclusions of this Phase I investigation into seawater hydraulic operation of the CCN-150 transfer pump system:

1. Demonstration of the conversion of the CCN-150 pump by replacement of the hydraulic motor is recommended as a means to identify how well the Fenner seawater motor matches the pump input torque and speed requirements. Lessons learned from this demonstration would serve as a design guide for full scale motor specifications for the seawater hydraulic CCN-150 transfer pump.

2. Consultation with the composites group at CDNSWC Annapolis, Maryland to assist NFESC in the development of a lighter weight Fenner motor and pump is recommended. Using the design information provided by the demonstration and CDNSWC's expertise in the application of composites technology, NFESC may be able to achieve additional weight savings for the CCN-150 transfer pump.

3. The current CCN-150 transfer pump system should be modified to reduce weight and increase pump and power source performance. NFESC recommends replacing the existing wire-braided reinforced hoses with equivalent rated thermoplastic hose of 1-inch-diameter supply, 1.25-inch-diameter return, and 0.5-inch-diameter case drain. A gradual replacement program would minimize the cost of this conversion. All teams would need to change in order to maintain equipment interchangeability.

4. Investigation into the application of non-return, open circuit seawater hydraulic system design for the smaller USCG operated equipment is recommended. A feasibility study, similar in scope to this study, is recommended as a first means to identify the nature of this equipment and the advantages for seawater hydraulic operation.

REFERENCES

1. J. Kunsemiller and S. Black. "Case Study of an Environmentally Safe Diver Tool System," Presented at the Underwater Intervention Conference, San Diego, CA, Feb 1994.

2. H.K. Telegadas. CARDEROCKDIV-SSM-64-94/07: Feasibility of using composite materials to reduce the weight of the CCN-150 transfer pump, Mar 1994.

3. Naval Sea Systems Command. NAVSEA S0300-A6-MAN-050: U.S. Navy ship salvage manual, Volume #5 (POL Offloading), 31 Jan 1991.

4. Naval Sea Systems Command. NAVSEA S6225-DX-MM0-010: Technical manual, Submersible pump subsystem CCN-150, 15 Aug 1980.

5. Naval Sea Systems Command. NAVSEA S0300-BR-MAN-010: Pollution response guide and equipment manual.

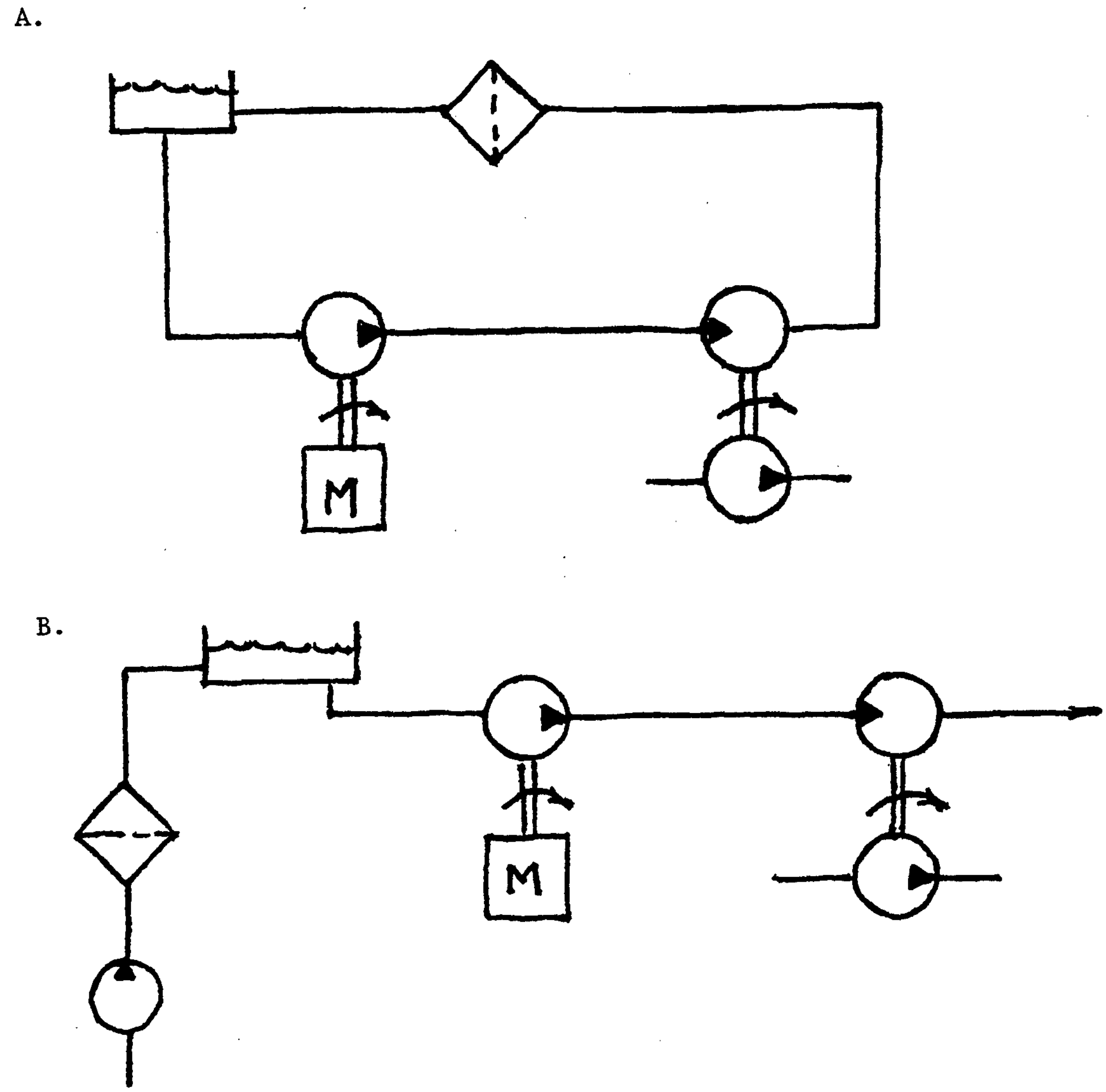

Figure 1. Open Circuit (a) and Non-return Open Circuit (b) Schematics.

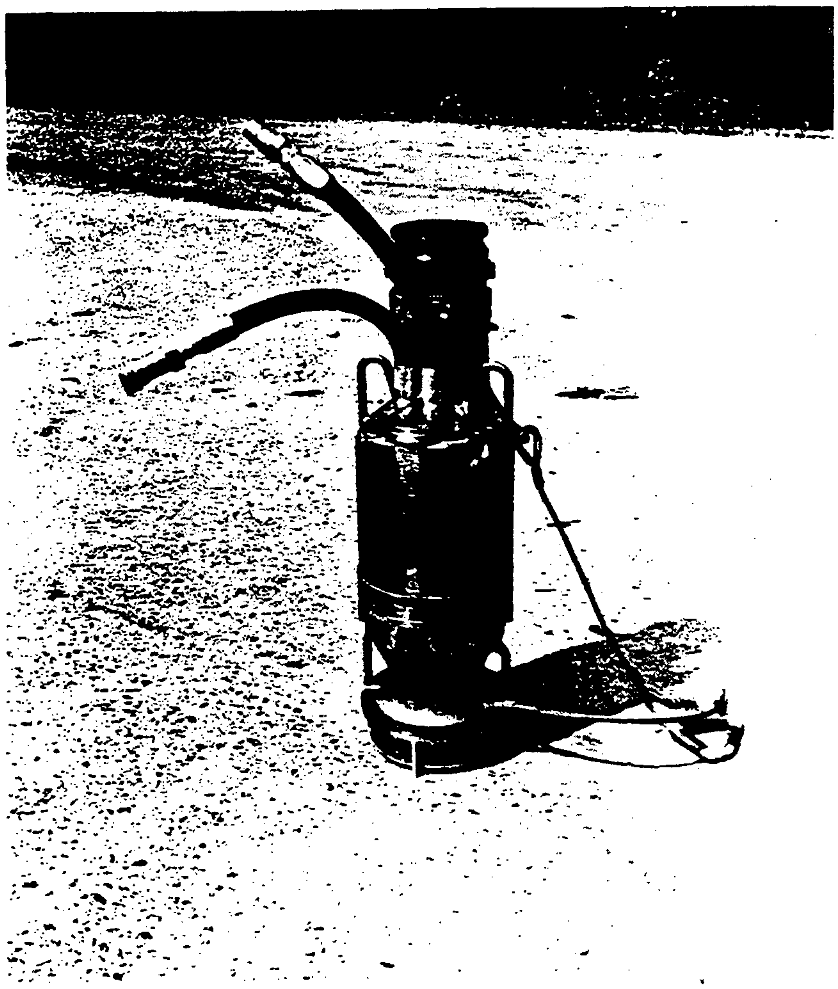

Figure 2. CCN-150 transfer pump.

HYDRAULIC SUPPLY CONDITIONS			
CURVE	A (WATER)	B (WARM OIL)	C (COLD OIL)
SUPPLY (PSIG)	2000-2300	2300-2400	2400
RETURN (PSIG)	125-130	95-100	75-85
OIL TEMP (°F)	120	100	100
FLOW RATE (GPM)	45-47	38-41	45-50

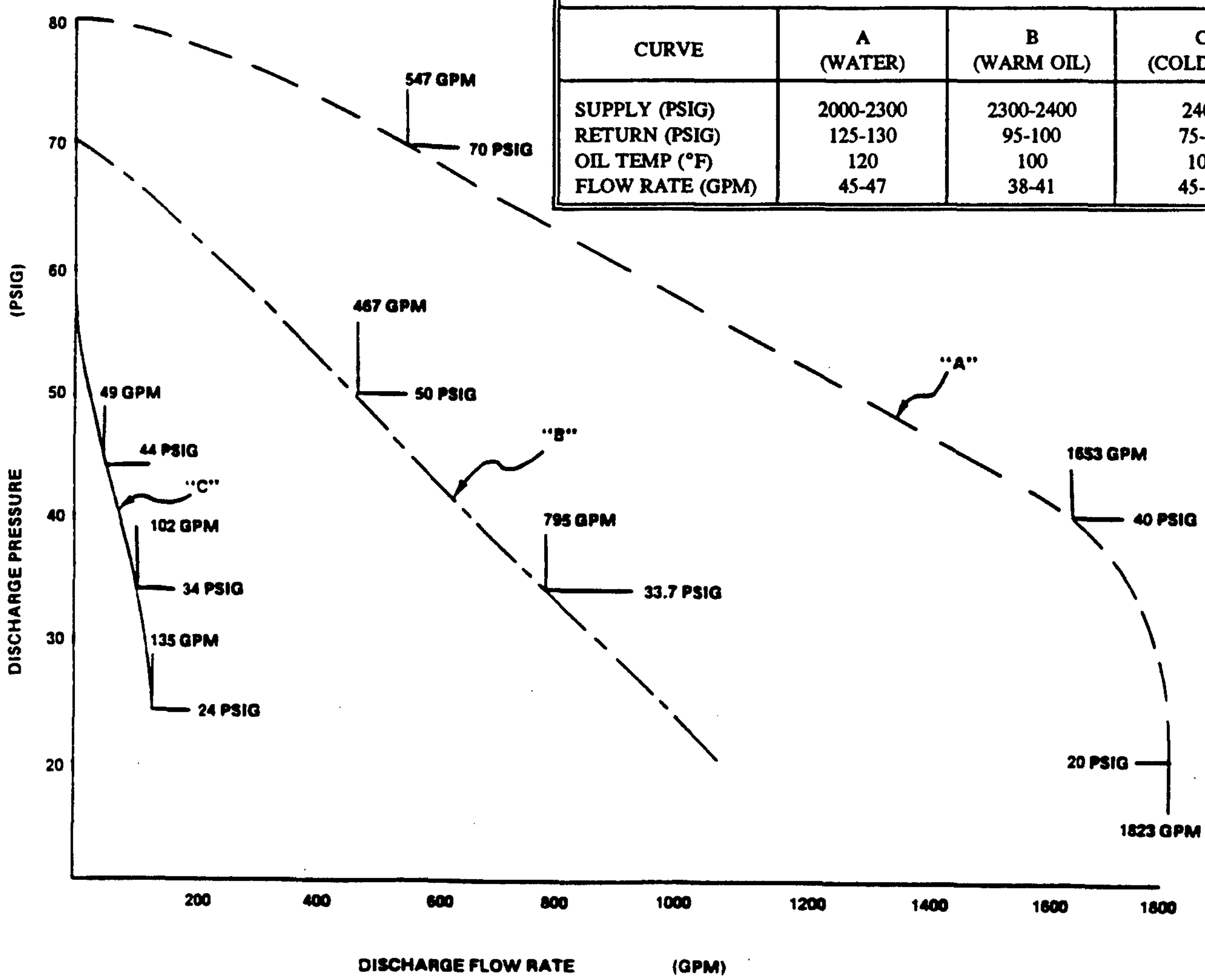

Figure 3. CCN-150 performance curves for water and oil.

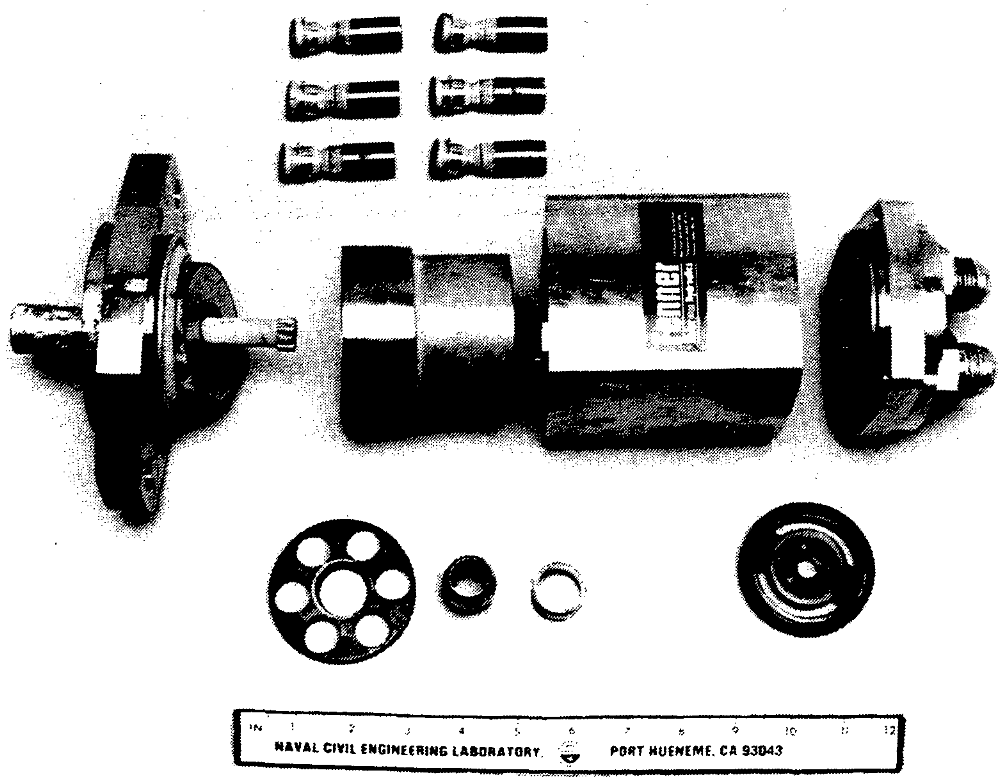

Figure 4. Fenner 7 hp seawater motor.

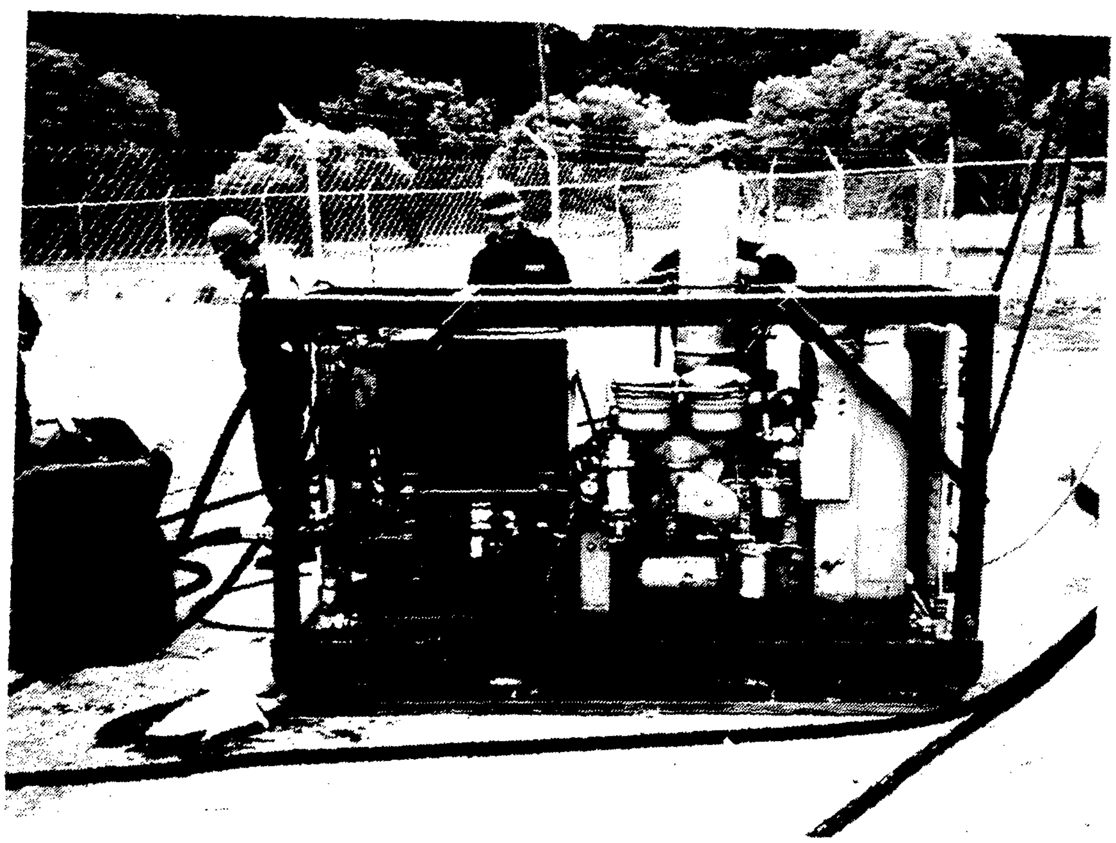

Figure 5. MOD 6 Hydraulic Power Source.

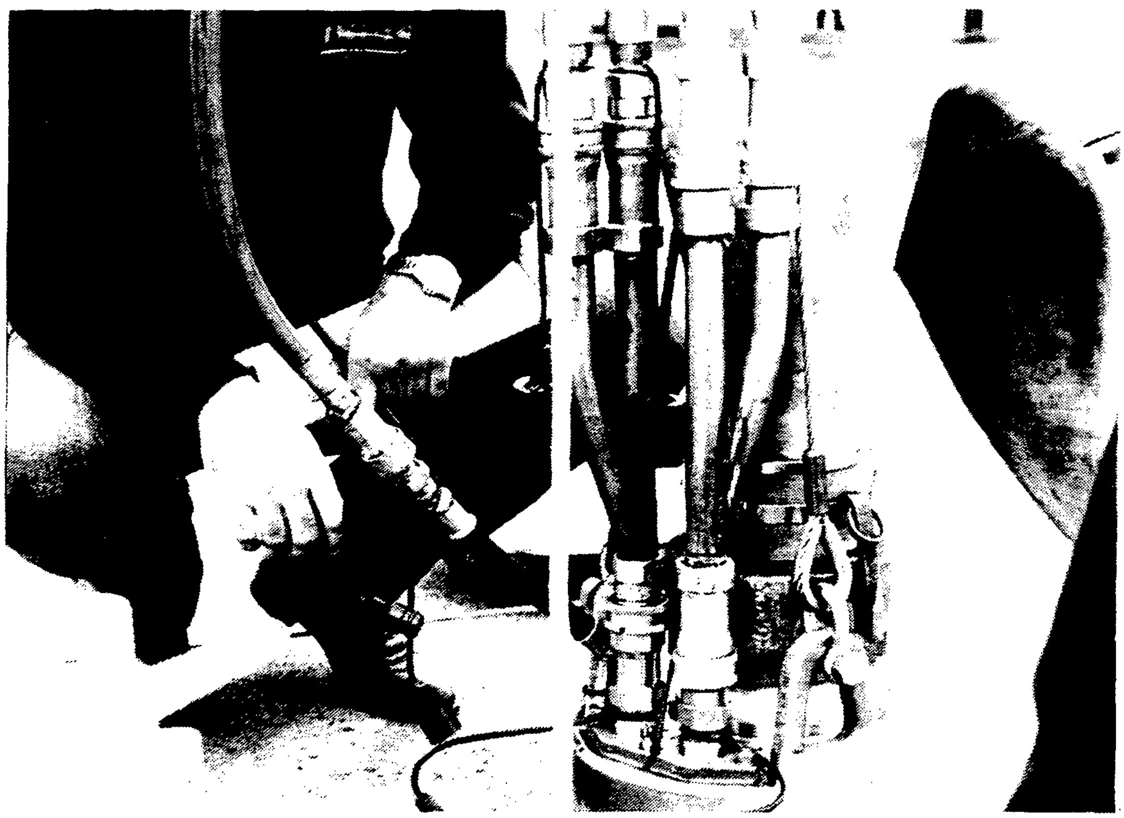

Figure 6. Manifold for CCN-150-5C to combine MOD 6 power source flow from dual hoses.

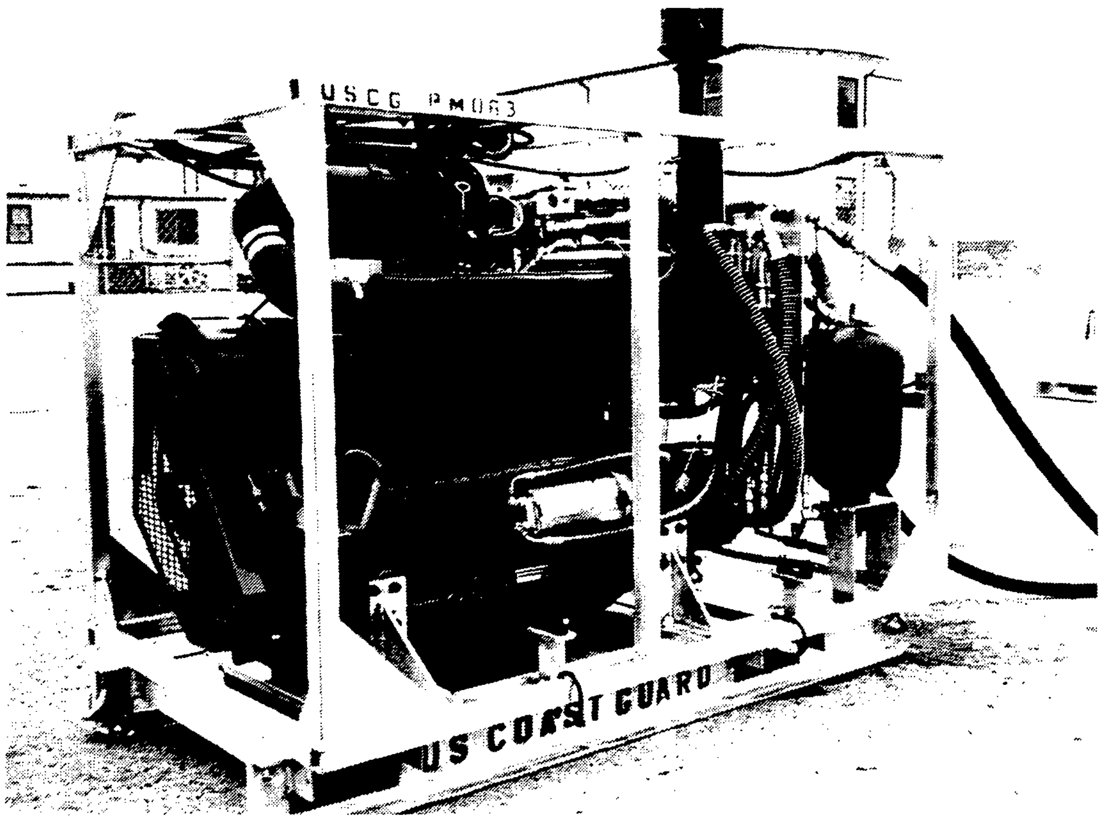

Figure 7. Hydraulic starter motor and associated accumulator on the Duetz power source.

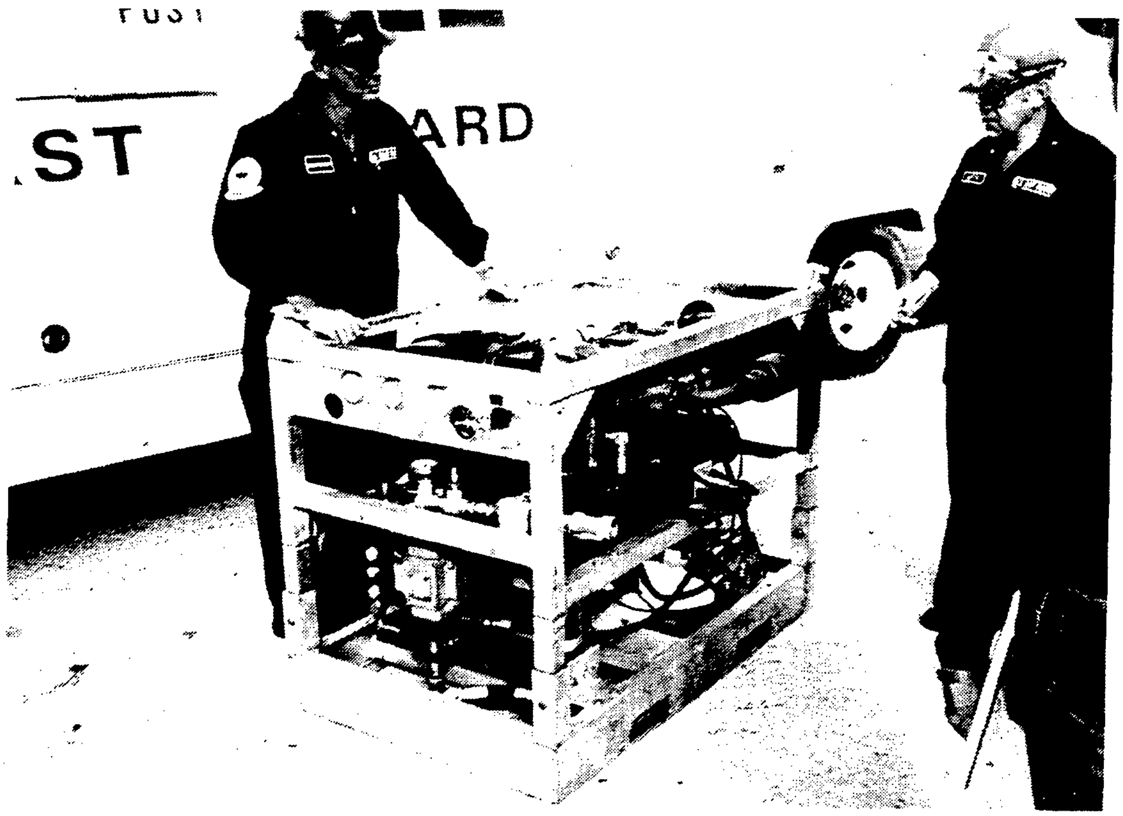

Figure 8. AVCO Type 3 Hydraulic Power Source.

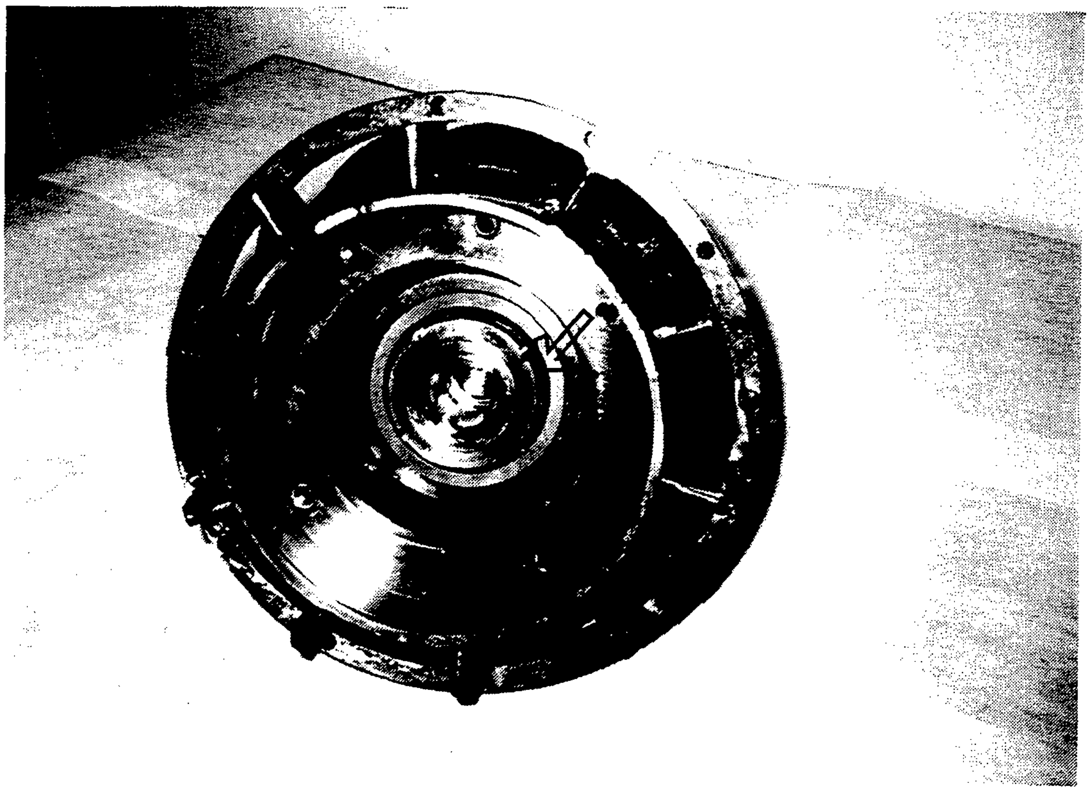

Figure 9. The CCN-150 pump shaft is supported by a heavy duty ball bearing at the motor end.

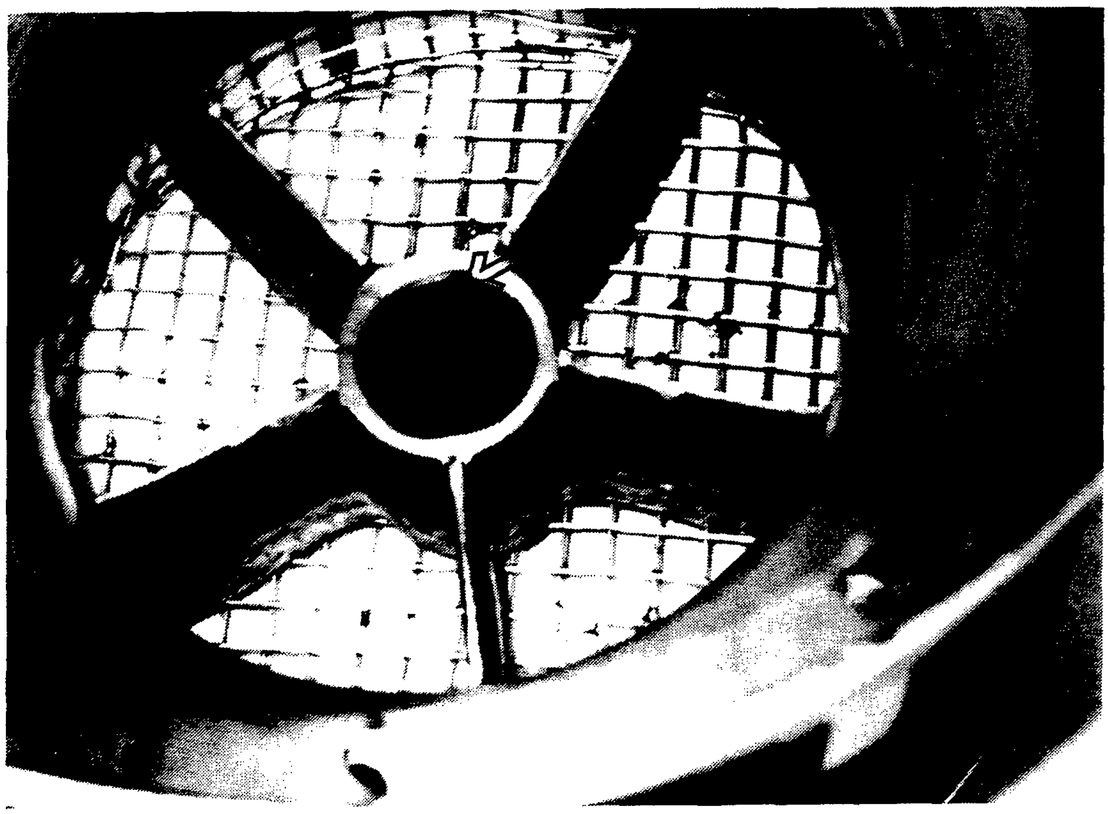

Figure 10. Damage to carbon impregnated bushing on CCN-150 lower impeller support.

Appendix A: Literature Survey Citations

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LITERATURE SEARCH CITATIONS

04359061 INSPEC Abstract Number: A9307-8745-050, C9304-1290L-013
Title: A comparison of muscle with artificial actuators

04230217 INSPEC Abstract Number: A9219-8630R-035
Title: Final design of a free-piston hydraulic advanced Stirling conversion system

04051932 INSPEC Abstract Number: B9202-8510-068, C9202-3350G-017
Title: Brushless motor drives injector's hydraulics

03957390 INSPEC Abstract Number: A91112222, B91060914
Title: Preliminary design of an advanced Stirling system for terrestrial solar energy conversion

1424875 NTIS Accession Number: PB90-851791/XAB
Hot Melt Adhesives: Applications. May 1987-October 1989 (Citations from the Rubber and Plastics Research Association Database)
(Rept. for May 87-Oct 89)

03709709
Title: New thermal insulations for CDTM bundles: foamed polyurethanes and silica sphere slurries
Conference Title: 25th Annual Offshore Technology Conference

03640668
Title: Thermoreactive water-soluble polymers, nonionic surfactants, and hydrogels as reagents in biotechnology

03640018
Title: Design, development, and demonstration of a high-pressure, overcenter, variable-displacement hydraulic motor

03633412
Title: Welding high pressure sea water pumps

03619053
Title: Choose the right hydraulic pump to assure machine uptime

03397762
Title: Development of the electronically controlled hydraulic cooling fan system.
Conference Title: Passenger Car Meeting and Exposition

03097047
Title: New series of petroleum production pump installations.

03042937
Title: Efficiency and pressure recovery in hydraulic jet pumping of two-phase gas/liquid mixtures.

02984700
Title: High pressure water-abrasive jet cutting for steel pipes of gas well casings.
Conference Title: Proceedings of the 5th American Water Jet Conference

02984670
Title: High pressure hydromilling of concrete surfaces.
Conference Title: Proceedings of the 5th American Water Jet Conference

02864465
Title: 25 kW(E) free-piston Stirling hydraulic engine for terrestrial solar thermal applications.
Conference Title: Proceedings of the 23rd Intersociety Energy Conversion Engineering Conference

0323974 94R-02830
Subfile: R
Biodegradable fluids; flow and filtrability tests

0317069 93R-04010
Subfile: R
Water hydraulic pumps for a safer and cleaner future

0304248 92S-01050
Subfile: S
H&H Pump introduces new sand dredging technology

0301255 91T-01525
Subfile: T
Lubrication characteristics of oil-hydraulic piston pump motor. Part 2: measurement of oil film thickness between piston and cylinder

0301111 91S-05694
Subfile: S
Testing of composite pipes in high velocity seawater

0267015 91T-01393
Subfile: T
Lubrication of Oil-hydraulic piston pump/motor. Part 1: Measurement of piston friction force

0241279
Subfile: FP
Engel accelerates development. Practical experience with the hydraulic concept for injection moulding machines

0241100
Subfile: PL
Sour-gas gathering system installs emergency shutdown valves

0240554
Subfile: FP
Prospects in construction. Bauma previews: development trends in hydraulics.

0238235
Subfile: FP
Shop window of the state of the art of components.

2455440 3417338
M/ SYSTEM AND METHOD FOR REGULATING THE SPEED OF A STEAM TURBINE BY CONTROLLING THE TURBINE VALVE RACK ACTUATOR

2454974 3416872
M/ APPARATUS FOR EXCAVATING EARTHEN MATERIAL BY EVACUATION OF SAME

2453187 3415601
M/ HYDRAULIC CONTROL SYSTEM

2451050 3414109
M/ HYDRAULIC CIRCUIT FOR SWIVEL WORKING MACHINE

2449172 3412874
M/ DOWNHOLE PUMP OF CONSTANT DIFFERENTIAL HYDRAULIC PRESSURE

2449168 3412870
M/ POWER STEERING PUMP WITH BALANCED PORTING

2446911 3411257
M/ HYDRAULIC BRAKE SYSTEM INCLUDING SLIP CONTROL

2442532 3408040
M/ DIRECT HYDRAULIC DRIVE FOR LARGE FLOTATION CELLS

2440714 3406737

M/ COMBINED ANTISKID AND TRACTION CONTROL ELECTRONIC BRAKE SYSTEM
2440401 3406424
M/ HYDRAULIC CIRCUIT FOR RUNNING A CRAWLER VEHICLE

2434313 3402015
M/ HYDRAULICALLY ACTUATED AIRCRAFT ENGINE CONTROL SYSTEM

2425918 3374598
M/ SLURRY HAULING VEHICLE

2423909 3373113
M/ POWER STEERING PUMP WITH BALANCED PORTING

2414787 3366624
M/ METHOD AND APPARATUS FOR HEATING AN ASPHALT PAVING SCREED

2407898 3361609
M/ VARIABLE MOMENT VIBRATOR USABLE FOR DRIVING OBJECTS INTO THE GROUND

2396949 3353853
M/ HYDRAULIC CIRCUIT WITH COMPENSATOR VALVE BIASED WITH HIGHEST PRESSURE ACTING ON ACTUATORS

2393039 3351268
M/ REGENERATIVE THERMAL OXIDATION APPARATUS AND METHOD

2392713 3350942
M/ VOLTAGE CONTROLLED HYDRAULIC SETTING TOOL

2390235 3349125
M/ COMBINED MARINE REFRIGERATING AND AIR CONDITIONING SYSTEM USING THERMAL STORAGE

2379521 3341570
M/ PLURAL HYDRAULIC PUMP SYSTEM WITH UNLOADING VALVE

2379471 3341520
M/ SYSTEM FOR AUTOMATICALLY OPENING AND CLOSING DOORS OF VEHICLES

2377293 3339989
M/ COMPRESSOR ARRANGEMENT SUITABLE FOR TRANSPORT REFRIGERATION SYSTEMS

2373398 3337396

M/ VARIABLE SPEED HYDRAULIC PUMP SYSTEM FOR LIQUID TRAILER

2358380 3326716
M/ ELECTRO-HYDRAULIC VEHICULAR POWER STEERING SYSTEM WITH CLOSED CENTER VALVING

2350081 3320860
M/ MULTIFUNCTION INTEGRATED POWER UNIT AND POWER TRANSFER APPARATUS THEREFOR

2349921 3320700
M/ HYDRAULIC ENERGY SUPPLY CART

2345742 3317747
M/ ON-OFF PRESSURE CUTOFF CONTROL FOR A VARIABLE DISPLACEMENT HYDRAULIC PUMP

2345161 3317166
M/ HYDRAULIC-MOTOR DRIVE CIRCUIT SYSTEM WITH ANTI-CAVITATION CONTROL

2337762 9304762
C/ MOTION CONTROLLER FOR WASTEWATER TREATMENT TRICKLING FILTER

2337563 3311870
M/ VARIABLE CAPACITY PUMP CONTROLLER OF HYDRAULICALLY DRIVEN WHEEL

2332756 3308255
M/ INTEGRATED PRESSURE AMPLIFICATION AND MODULATION SYSTEM FOR A HYDRAULIC CIRCUIT

2331043 3307019
M/ CONTROL AND REGULATING DEVICE FOR A HYDROSTATIC TRANSMISSION

2330934 3306910
M/ AUTOMATIC SWIMMING POOL COVER WITH A DUAL HYDRAULIC DRIVE SYSTEM

2329793 3306246
M/ COMBINED CENTRIFUGAL AND UNDERVANE-TYPE ROTARY HYDRAULIC MACHINE

2324100 3302113
M/ HYDROSTATIC BRAKING POWER CONVERTER

2322114 3300723
M/ HYDRAULIC PUMP

2319823 3276814
M/ AUTOMATIC TWO-POSITION FOUR-WAY PULSATING VALVE

2319616 3276607
M/ ELECTRICALLY ACTUATED AND CONTROLLED AUXILIARY HYDRAULIC SYSTEM FOR SKID STEER LOADER

2312292 3271327
M/ RECIPROCATING HYDRAULIC PUMP

2312266 3271301
M/ SLURRY DISTRIBUTION SYSTEM USING REMOTE DISTRIBUTORS

2310485 3270080
M/ RECIPROCATING HYDRAULIC PUMP

2309749 3269344
M/ MOBILE CLEANING UNIT

2307727 3267853
M/ AXLE DRIVING APPARATUS WITH VARIABLE DEPTH CRESCENT OIL PASSAGES

2299900 3262094
M/ FLOW LOADING UNLOADER VALVE

2297692 3260433
M/ ROTARY MOTOR/PUMP

2290180 9223257
C/ DRIVING AND SUPPLY UNIT FOR A COOLER

2287866 3253243
M/ RAM AIR TURBINE DRIVING A VARIABLE DISPLACEMENT HYDRAULIC PUMP

2276757 3245017
M/ ACTIVE HYDRAULIC PRESSURE CONTROL

2270912 3240804
M/ HYDRAULIC SYSTEM IN AN INJECTION MOLDING MACHINE

2270561 3240453

M/ MULTI-LANCE TUBE CLEANING SYSTEM HAVING FLEXIBLE PORTIONS
2261843 3233947
M/ DEVICE FOR PRESSURE-REGULATED VARIABLE DISPLACEMENT MOTORS WITH RPM-DEPENDENT SET PRESSURE COMPENSATION

2261780 3233884
M/ PLATING APPARATUS FOR CONSTRUCTING OR REPAIRING A PALLET

2256034 9213424
C/ CLEANING METHOD; PRESSURIZATION OF LIQUID WITH GAS DRIVEN HYDRAULIC PUMP

2246503 3223180
M/ METHOD OF AND APPARATUS FOR HYDRAULICALLY DEFORMING A PIPE-SHAPED HOLLOW MEMBER

2246487 3223164
M/ HYDRAULIC DOOR ACTUATOR; OPENING AND CLOSING

2244580 3221943
M/ HYDRAULIC CLUTCH AND TRANSMISSION ACTUATING SYSTEM

2244543 9209737 3221906
CM/ WELL CEMENTING METHOD USING A DISPERSANT AND FLUID LOSS INTENSIFIER; INJECTING ETHOXYLATE AND SULFONATED DISPERSANT BLEND AND ALCOHOL

2244280 3221643
M/ HYDRAULIC UNIT FOR DRIVING A TOOL

2240570 3219222
M/ INTEGRAL PRESSURE PULSE ATTENUATOR

2233391 3213982
M/ HYDROSTATIC TRANSMISSION

2231613 3212719
M/ HYDROSTATIC TRANSMISSION WITH INTERCONNECTED SWASH PLATE NEUTRAL VALVE AND BRAKE UNIT

2225718 3208751
M/ HYDRAULIC APPARATUS INCLUDING A HYDRAULIC FLUID FLOW CONTROL CARTRIDGE

2220103 3204728

M/ HYDRAULIC DEVICE FOR OPERATING A CLUTCH IN AN INDUSTRIAL VEHICLE
2212101 3178010
M/ STEERING SYSTEM FOR VEHICLES

2204007 3172221
M/ FLUID SUPPLY SYSTEM FOR VEHICLES

2202333 3171080
M/ MULTI-LANCE TUBE CLEANING SYSTEM

2200153 3169428
M/ HYDROSTATIC CONTINOUSLY VARIABLE TRANSMISSION WITH ADJUSTABLE CLUTCH VALVE

2192526 3163816
M/ MODULATOR AND POWER-ASSISTED STEERING CIRCUIT CONTAINING SUCH A MODULATOR

2181268 3155114
M/ FLUID JET SYSTEM AND METHOD FOR UNDERWATER MAINTENANCE OF SHIP PERFORMANCE

2181118 3154964
M/ HYDROSTATIC TRANSMISSION

2176811 3151734
M/ PERFORATING GUN PRESSURE BLEED DEVICE

2174574 3150041
M/ HYDRAULIC REGENERATIVE STARTER/SPEED REGULATOR FOR A GUN GAS POWERED GATLING GUN

2166976 3144518
M/ BYPASS MODE CONTROL FOR HIGH PRESSURE WASHING SYSTEM

2164686 3142781
M/ CAR WASH ADJUSTABLE TO CAR SIZE

2164402 3142497
M/ VACUUM DRYING MACHINE WITH MULTIPLE TABLES FOR INDUSTRIAL HIDES AND SIMILAR PRODUCTS

2162687 3141336
M/ MULTI-LANCE TUBE CLEANING SYSTEM HAVING SLIDING PLATE

2162686 3141335
M/ PORTABLE UNITARY AIRCRAFT AIR CONDITIONER AND HEATER

2158921 9114887
C/ WATER RAKE

2152587 3133795
M/ MULTI-HOSE FLEXIBLE LANCE TUBE CLEANING SYSTEM; CLEANING HEAT EXCHANGER TUBES

2148154 3130448
M/ METHOD AND APPARATUS FOR PERIODIC CHEMICAL CLEANINGS OF TURBINES

2142309 3126227
M/ METHOD AND APPARATUS FOR APPLYING PREGERMINATED PLANTLETS

2136673 3122226
M/ HYDRAULIC PUMP WITH PULSATING HIGH AND LOW PRESSURE OUTPUTS

2136647 3122200
M/ REFUSE COLLECTION SYSTEM, REFUSE COLLECTION TRUCK AND LOADER ASSEMBLY THEREFOR

2135993 3121546
M/ HYDRAULIC DRIVE FOR PULL THROUGH DOCTOR BLADE TRANSFER SYSTEM

2134793 3120888
M/ HYDRAULIC POWER SYSTEM FOR OUTBOARD MOTOR

2134361 3120456
M/ HIGH TORQUE HYDRAULIC SHOE BOLT WRENCH

2132564 3119046
M/ VIBRATORY CORE DRILL APPARATUS FOR THE RECOVERY OF SOIL OR SEDIMENT CORE SAMPLES

2130461 3117488
M/ MULTI-LANCE TUBE CLEANING SYSTEM

2130305 3117332
M/ PRESSURIZED FLUID MECHANISM WITH TWO CUBIC CAPACITIES AND CLOSED CIRCUIT APPLYING SAME

2130242 3117269
M/ HYDRAULIC FLUID CIRCUIT FOR FULL CASE HYDRAULIC UNIT

2118638 3108783
M/ PUMP-ACTUATING MECHANISM

2116624 3107324
M/ CENTERING DEVICE THAT CAN BE ENGAGED OR DISENGAGED, SPECIFICALLY FOR A DRILLING ASSEMBLY

2112615 3104228
M/ HYDRAULIC CIRCUIT FOR BACKHOE

2108947 3101717
M/ MODULATOR AND POWER-ASSISTED STEERING CIRCUIT COMPRISING SUCH A MODULATOR

2107147 3100485
M/ VARIABLE DRIVE APPARATUS

2101692 3069539
M/ HIGH-PRESSURE HYDRAULIC GUN

2100108 3068409
M/ HYDROSTATIC DRIVE FOR WAVE GENERATING SYSTEMS IN SWIMMING POOLS

2093795 3063434
M/ HYDRAULIC SYSTEM FOR LAUNDRY FLATWORK IRONER

2093183 3062823
E/ ACTUATOR MECHANISM FOR A HIGH-VOLTAGE CIRCUIT BREAKER

2092555 3062728
M/ HYDRAULIC GEAR MOTOR

2092198 3062371
M/ POWERED ACCESS PLATFORM UNITS

2091878 3062051
M/ HYDROSTATICALLY OPERATED CONTINUOUSLY VARIABLE TRANSMISSION

2076101 3050899
M/ MULTI-ACTUATOR HYDRAULIC PRESS

2072112 3047979
M/ ELECTRICALLY CONTROLLED AUXILIARY HYDRAULIC SYSTEM FOR A SKID STEER LOADER

2065996 3043370
M/ FASTENER TESTER

2064590 3042349
M/ AUXILIARY POWER STEERING SYSTEM

2048829 3030583
M/ CONTROL APPARATUS FOR DOUBLE ACTING HYDRAULIC CYLINDER UNITS

2047712 9011217
C/ SIEVE DEVICE FOR SIEVING OUT COMPOST FROM ROTTEN ORGANIC MATERIAL

2044778 3027631
M/ SELF POWERED DRIVE SYSTEM FOR A GATLING TYPE GUN

2029893 3016600
M/ HYDRAULIC DOOR OPENING OR CLOSING DEVICE

2028246 3015507
M/ DEVICE FOR THE ACCELERATION OF BODIES, ESPECIALLY A MOBILE CATAPULT FOR FLYING BODIES

2024068 3012322
M/ EJECTOR MECHANISM FOR AN AMMUNITION CARRIER

2022138 3010953
M/ HYDRAULIC MOTORS AND VEHICLE HYDROSTATIC TRANSMISSION SYSTEM OF WHEEL MOTOR TYPE

2019603 3008972
M/ HARVESTING, SHUCKING AND EVISCERATING CLAMS AT SEA

2015957 3006302
M/ VARIABLE RATIO STEERING MECHANISM

2012943 3004146
M/ ROTARY SPRAY DEVICE

2011260 3002886
M/ PRESSURE SPIKE SUPPRESSING APPARATUS

2009347 3001396
M/ HYDRAULICALLY OPERATED CONTINUOUSLY VARIABLE TRANSMISSION

2009345 3001394
M/ HYDRAULICALLY POWERED ACTUATOR FOR MAINTAINING A MEMBER UNDER PRELOAD

2009344 3001393
M/ FREE PISTON ENGINE-PUMP PROPULSION SYSTEM

2008439 9000122
C/ DESALINATION PROCESS; ENERGY EFFICIENT

1999907 2969408
M/ HYDRAULIC WHEEL MOTOR AND PUMP

1994198 2965247
E/ CLOSED FEEDBACK INJECTION SYSTEM FOR RADIOACTIVE MATERIALS USING A HIGH PRESSURE RADIOACTIVE SLURRY INJECTOR

1991511 2963588
M/ VARIABLE DISPLACEMENT PORT PLATE

1988372 2961482
M/ HYDRAULIC PUMPS OR MOTORS AND HYDROSTATIC TRANSMITTING SYSTEMS

1983188 8921975
C/ METHOD OF AND INSTALLATION FOR CLEANING MOTOR VEHICLES

1980643 2955976
M/ VEHICLE ANTI-LOCK BRAKE SYSTEM

1980056 2955389
M/ COMBINED AUXILIARY AND EMERGENCY POWER UNIT

1975799 2952338
M/ CLUTCH/BRAKE UNIT WITH SELF-CONTAINED ACTUATING PUMP SYSTEM

1975477 2952016
M/ STATIC HYDRAULIC PRESSURE TYPE CONTINUOUSLY VARIABLE TRANSMISSION

1973623 2950761
M/ AGRICULTURAL WATER CANNON

1971273 2949014
M/ AUTOMATED MECHANICAL TRANSMISSION SYSTEM FOR USE IN COMMERCIAL VEHICLES

1971190 2948931
M/ MULTI-LANGE TUBE BUNDLE CLEANER

1970924 2948665
M/ HYDRAULICALLY OPERATED CONTINUOUSLY VARIABLE TRANSMISSION

1968624 2946966
M/ HYDROSTATICALLY OPERATED CONTINUOUSLY VARIABLE TRANSMISSION

1965011 2944459
M/ HYDRAULIC GEAR PUMP

1959887 2940535
M/ HYDRAULIC CIRCUIT FOR USE IN WIRELINE FORMATION TESTER

1959856 2940504
M/ STATIC HYDRAULIC CONTINUOUSLY VARIABLE TRANSMISSION

1957683 2938929
M/ COMPACT HIGH-TORQUE APPARATUS AND METHOD FOR ROTATING PIPE

1954001 2936290
M/ HYDRAULIC PUMP ASSEMBLY ASSOCIATED WITH ACCUMULATOR

1951714 2934582
M/ OVERTRAVEL STOP ACTIVATED CONTROL VALVE

1951472 2934340
M/ ARRANGEMENT FOR REVERSING PRESSURE OF CYLINDERS AND ROLLERS IN PRINTING MACHINES

1949133 2932581
M/ HYDRAULIC CIRCUIT IN AN INDUSTRIAL VEHICLE

1946976 2931012
M/ SELF-REGULATED HYDRAULIC CONTROL SYSTEM

1945476 2930092
M/ PLURAL HYDRAULIC PUMP SYSTEM WITH AUTOMATIC DISPLACEMENT CONTROL AND PRESSURE RELIEF VALVE

1945396 2930012
M/ APPARATUS FOR FEEDING AND METERING FLUID COMPONENTS TO A HIGH PRESSURE MIXING HEAD

1942939 2928134
M/ FLUID-PRESSURE ELEVATOR

1941152 2926925
M/ ROTARY COMPRESSOR WITH CLUTCH AND BYPASS CONTROL ACTUATED BY HYDRAULIC FLUID

1936833 2923765
M/ HYDRAULIC CONTINUOUS PRESS WITH IMPROVED DRIVE

1934190 2921700
M/ TECHNIQUE FOR PROVIDING AN UNDERGROUND TUNNEL UTILIZING A POWERED BORING DEVICE

1923736 2914032
M/ SUPERHIGH PRESSURE FLUID INJECTION APPARATUS

1907263 2901611
M/ DOUBLE-ACTING FORGING HAMMER AND METHOD

2476001 3432664
M/ HYDRAULIC PUMP OUTPUT PRESSURE COMPENSATION SYSTEM

2473486 3430703
M/ HIGH PRESSURE VISCOUS LIQUID PUMP

Appendix B: Fenner Literature

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Fenner

Water Hydraulics

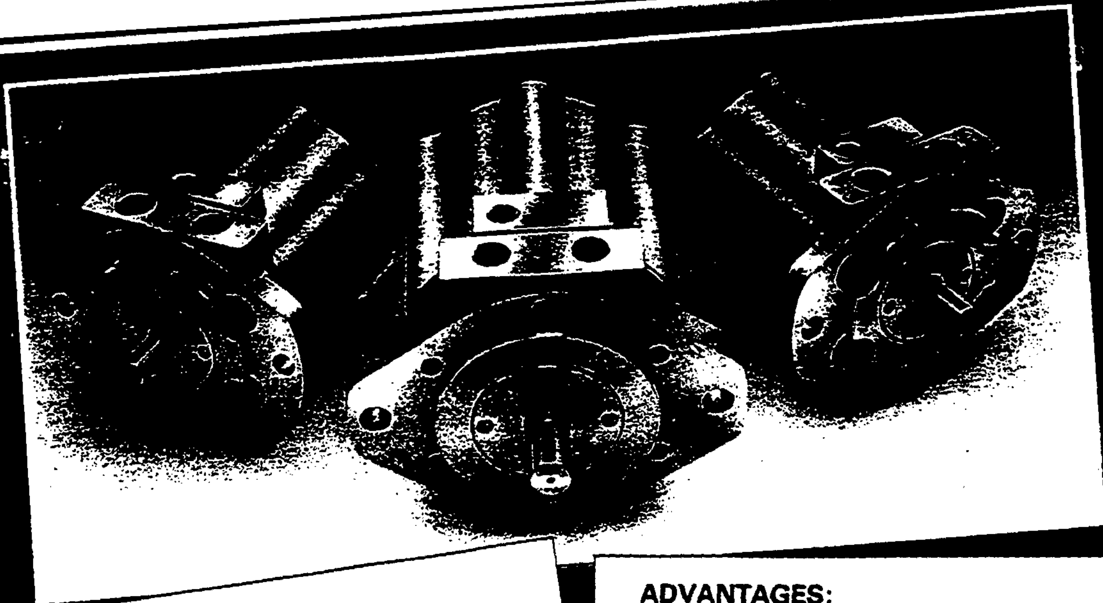
Axial Piston Water Pumps and Motors

Totally oil free, clean and completely safe for people, processes and products, the hydraulic pumps and motors of Fenner Water Hydraulics are playing a vital role in the drive against industrial pollution.

Based on axial piston designs, and offering low-cost operation, minimum cooling, easy maintenance and reduced system pressure losses, they are proving ideal for a wide variety of industrial uses.

As a result of employing advanced materials, high velocity and loaded sliding surfaces are now able to operate with water as their only lubricant, alleviating the need for an oil water interface and the possible contamination of the hydraulic system or the working environment.

Five sizes of pump and motor are now available. Future development includes tools, valves, circuit conditioning equipment and electronic controls for use on raw and seawater applications.



APPLICATIONS;

- SURFACE AND UNDERWATER VESSELS.
- DIVER AND R.O.V. TOOLS.
- MINING.
- ASSEMBLY LINE TRANSMISSION SYSTEMS.
- FOOD PROCESSING.
- SUBSEA CONTROL SYSTEMS.
- NUCLEAR POWER PLANTS.
- METAL, GLASS AND CHEMICAL PROCESSING.
- ROBOTICS.
- WINCH DRIVES.

ADVANTAGES;

- SAFETY ■ *Completely safe in pure form.*
- FLUID COST ■ *Cheap.*
- ENVIRONMENTAL ■ *No health or pollution risk.*
- CLEANLINESS ■ *Maintenance without mess.*
- DISPOSAL ■ *Down the drain.*
- COMPATIBILITY ■ *Safe for people, processes and products.*
- STORAGE ■ *On tap.*
- EFFICIENCY ■ *Reduced pressure losses in system.*
- SEALING ■ *Accidental leakage not hazardous.*
- COOLING ■ *Often not required.*
- COMPRESSIBILITY ■ *Comparable with other hydraulic fluids.*

RAW WATER PUMP/MOTOR CHARACTERISTICS

		UNITS				
		F06 (2)	F15 (2)	F30	F60	F120 (2)
DISPLACEMENT	cc/rev	6	15	29	63	120
SPEED	rpm	1500	1500	1500	1500	1500
DELIVERY/SUPPLY	l/min	9	22	40/48	86/103	180
PRESSURE	bar	140	140	140	140	140
TORQUE (3)	Nm	13	33	69/62	149/131	267
DIAMETER	cm	6.5	13	16	21	26
LENGTH	cm	11	15	19	24	30
WEIGHT (1)	kg	4.5	11	22	~~44~~ 24	88
POWER (3)	kW	2	5	11/10	23/20	42

(1) STAINLESS STEEL CASING (ALUMINIUM AND PLASTIC AVAILABLE FOR CRITICAL WEIGHT APPLICATIONS)
(2) VALUES ARE APPROXIMATE FOR THESE UNITS
(3) PUMP/MOTOR PERFORMANCE

Fenner Water Hydraulics offer a comprehensive application engineering and design service in support of our Water Hydraulic product range and technology. For further information of these services and products please contact Fenner Water Hydraulics.

Fenner
Water Hydraulics

J H FENNER & Co Ltd
MARFLEET, HULL HU9 5RA
TEL: 0482 781234
TELEX: 592686
FAX: 0482 701599

Appendix C: Danfoss Literature

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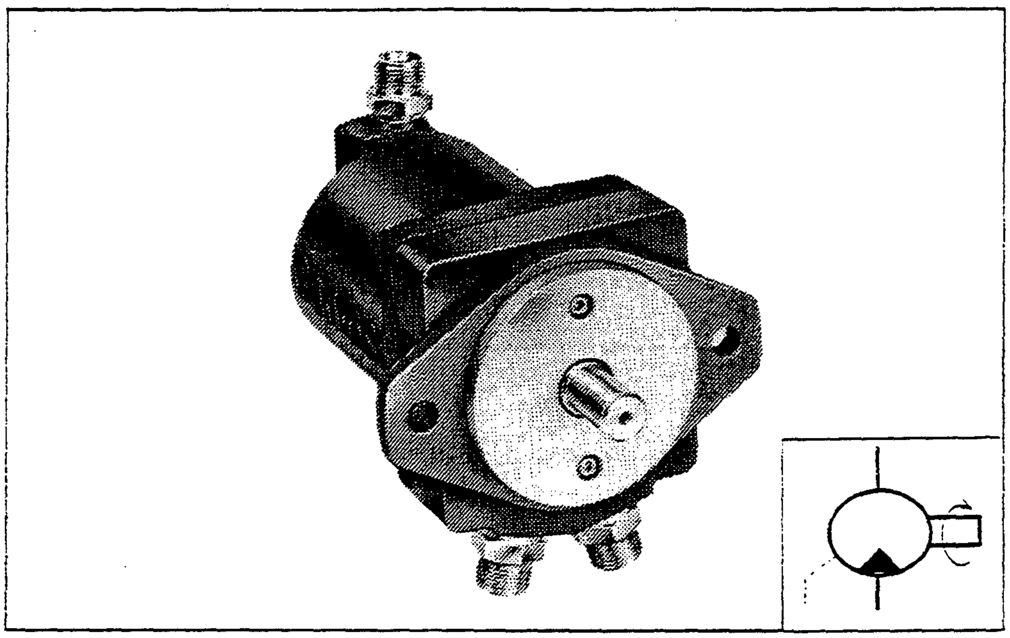
Nessie™ Motors
Type MAH 4/5 to 25/32

Introduction



Design and function

The MAH-motors are used when a rotating movement is required.
The motors are based on the axial piston principle, resulting in a very light and compact design compared to the output power.

The motors are designed so that the moving parts are water lubricated.
The motor is designed for ordinary water, i.e. without additives of any kind to the medium.

Advantages

* High pressure level, 140 bar
* Very compact and light motor => higher degree of freedom when placing the motor in a given application
* No oil lubrication
* Minimum service needed
* Long life time
* All outside parts of the motor are made of non-corrosive material (special coated aluminium)
* Owing to the smooth surfaces, it is easy to clean the outside of the motor

Motor variants

Sizes from 4 to 32 cm^3/rev with 6 different displacements are planned for the MAH-motors.

The first size to be introduced is 10/12.5 cm^3/rev.

Technical data

MAH type	4	5	10	12.5	25	32
Geometric displacem. (cm³/rev)			10	12.5		
Max. speed (min^{-1}) cont			3,000	3,000		
Max. torque (Nm) cont			21.5	26.5		
Max. power (kW) cont			6.7	8.3		
Max. pressure drop (bar) cont			140	140		
Max. water flow (l/min) cont			33	41		
Starting torque (Nm) @ max. press. drop cont			14.3	17.8		
Min. speed (min^{-1})			200	200		
Weight (kg)			3.9	3.9		

Drain line

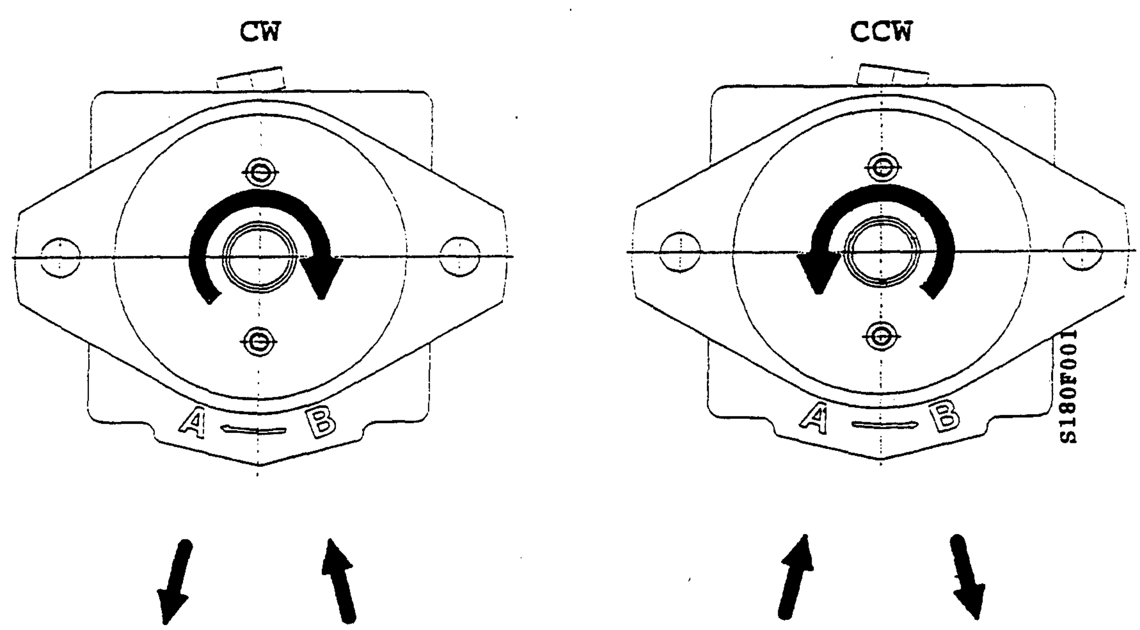
The motor shall always be fitted with a drain line.

Max. pressure in drain line: 5 bar.

Direction of rotation

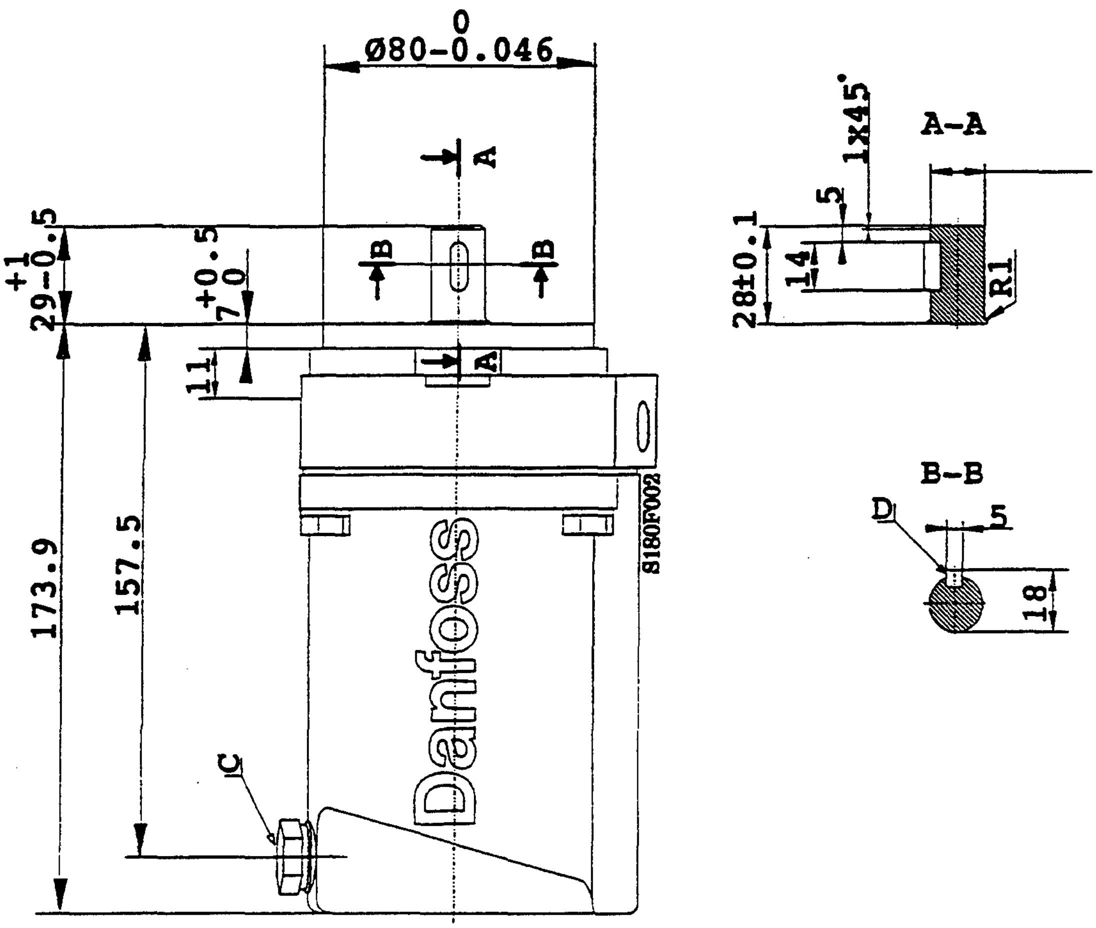
The MAH motors are uni-directional, but available in both cw- and ccw-versions.

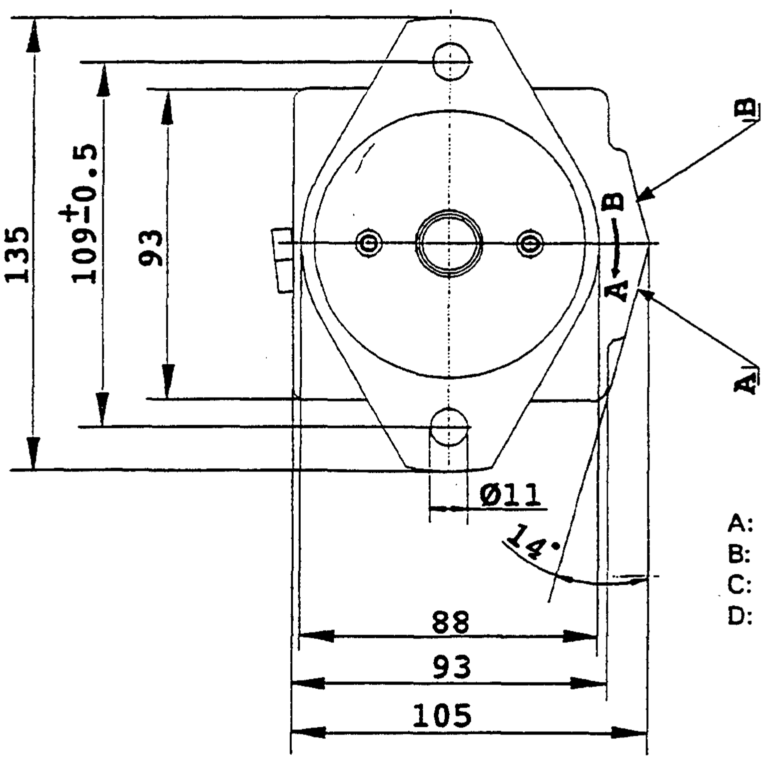
The direction of rotation is decided to be the same as the outlet shaft's direction of rotation, seen from the shaft towards the motor.



Please note: The motors are designed to be able to turn "the opposite" direction for a shorter period of time at a slightly lower efficiency.

Dimensions for MAH 10/12,5 (in mm)

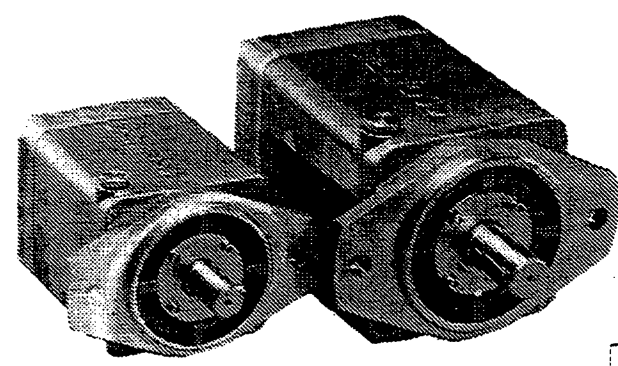


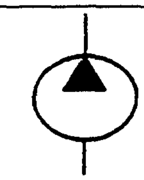


A: G3/8 x 13.5 deep
B: G3/8 x 13.5 deep
C: G1/4 x 13 deep
D: 5 x 5, DIN 6885

Nessie™ Pumps
Type PAH 25/32 and PAH 63/80

Introduction





Design and function

PAH 25/32 and 63/80 are pumps for establishing flow under high water pressure.

The pump is based on the axial piston principle, which enables a very light and compact design.

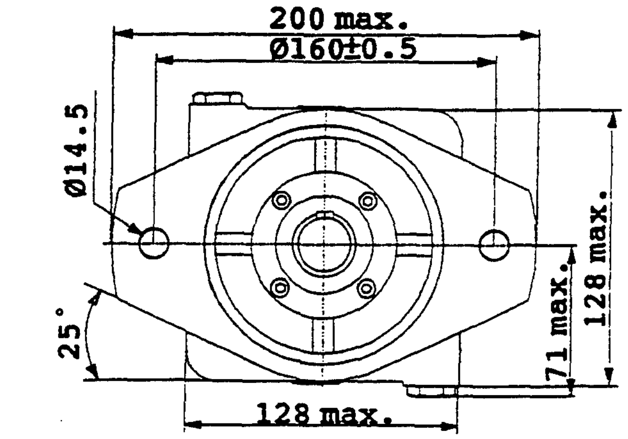
The pump is designed so that lubrication of the moving parts of the pump follows from the water itself.

All parts included in the pump are designed for a long life time. This means a long life time with a constant good efficiency, and in general a minimum of service is needed.

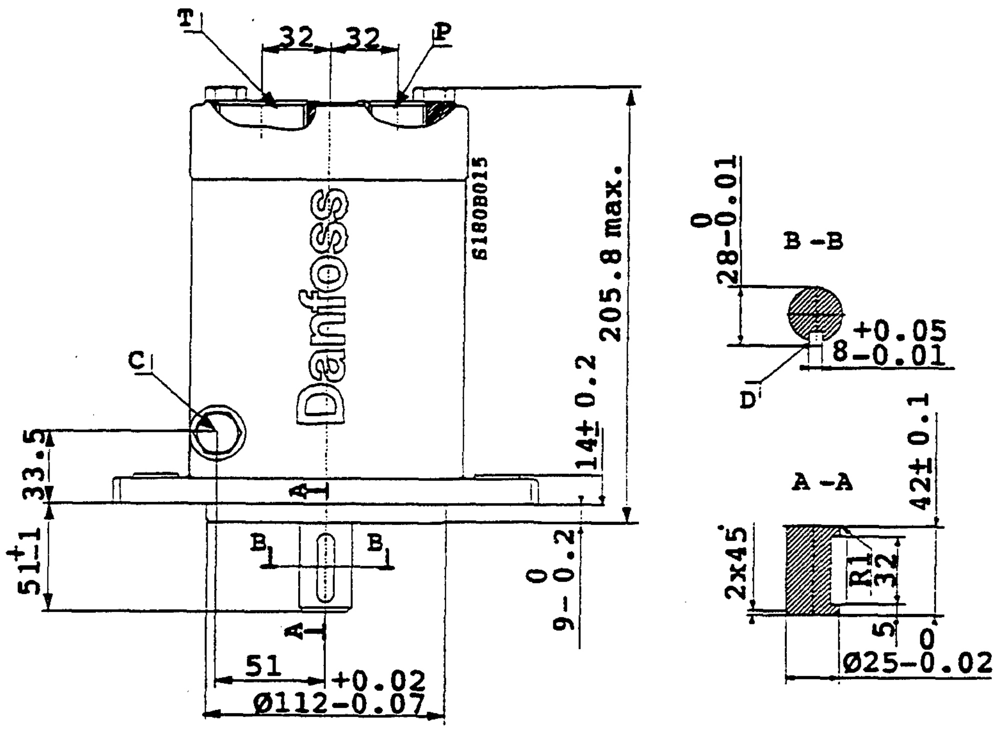
Advantages

* Very compact and light pump (can be installed in direct connection with the electrical motor)
* Minimum service needed (periodic service including oil changes and replacement of wear parts disappears)
* Long life time
* All outside parts of the pump are made of non-corrosive material (brass) and the surface is easy to clean

Dimensions for PAH 25 and PAH 32



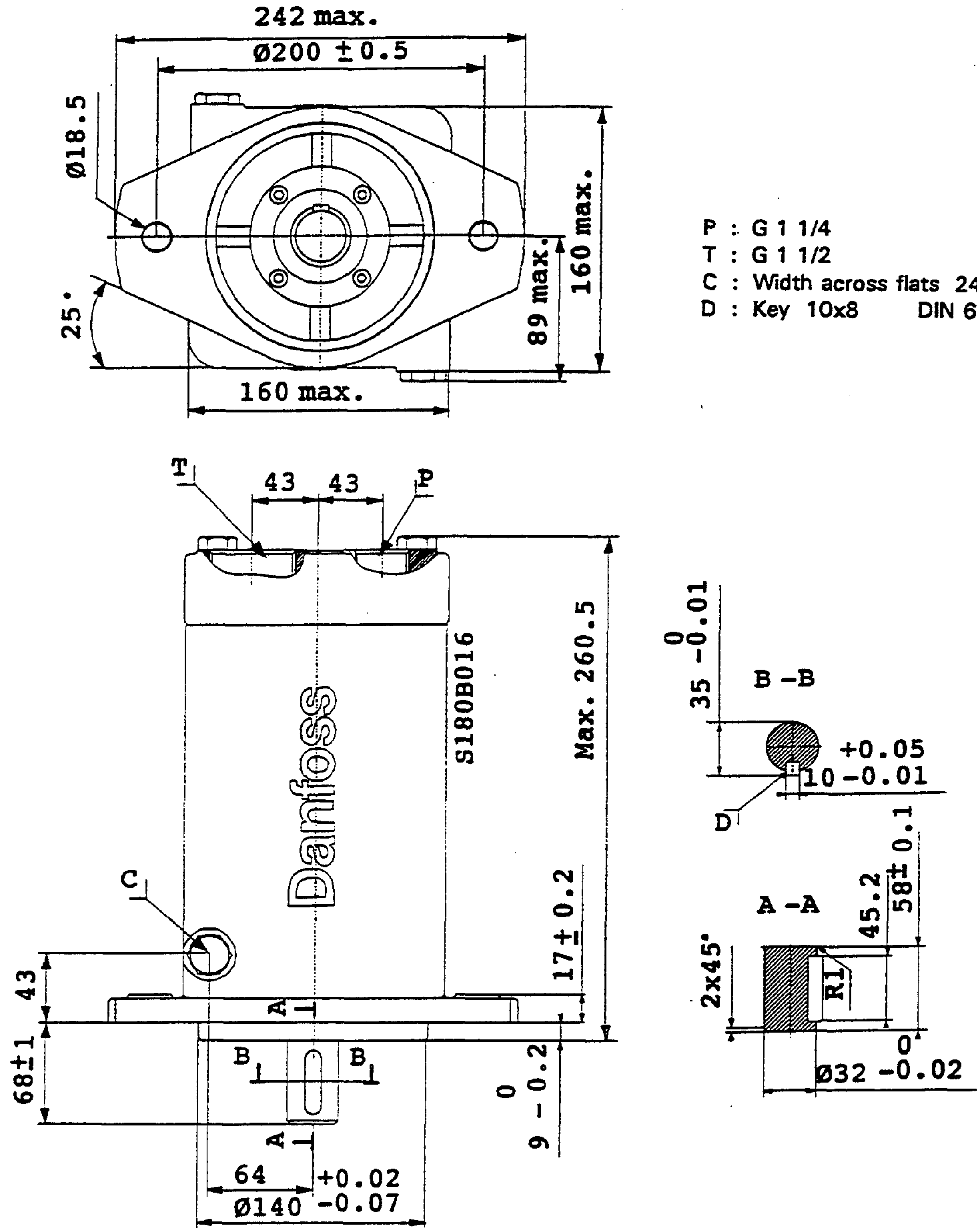
P : G 3/4
T : G 1 1/4
C : Width across flats 19
D : Key 8x7 DIN 6885



Technical data

PAH type	25	32	63	80	
Geometric displacement	25 cm³/rev	32 cm³/rev	63 cm³/rev	80 cm³/rev	
Max. pressure, cont.	160 bar	160 bar	160 bar	160 bar	2350 psi
Max. speed, cont.	1,500 rpm	1,500 rpm	1,500 rpm	1,500 rpm	
Min. speed	700 rpm	700 rpm	700 rpm	700 rpm	
Max. flow, cont. at max. pressure	34 l/min	44 l/min	86 l/min	112 l/min	29 gal/min
Max. power requirement	10,5 kW	13 kW	26 kW	33 kW	44 hp
Weight	18 kg	18 kg	37 kg	37 kg	81 lb

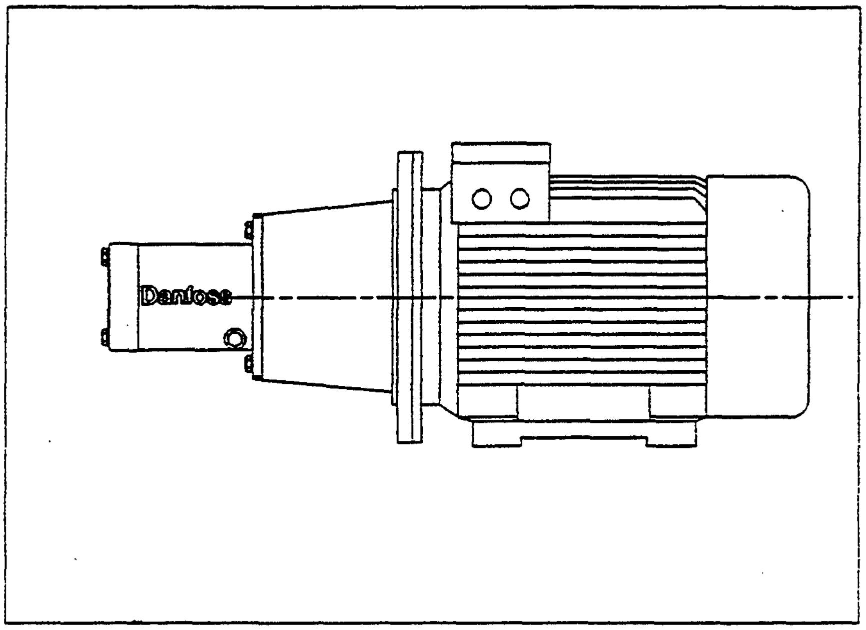
Dimensions for PAH 63 and PAH 80



P : G 1 1/4
T : G 1 1/2
C : Width across flats 24
D : Key 10x8 DIN 6885

Mounting

The pump is connected to the electrical motor by means of a bell-housing and an elastic coupling on the input shaft.
Direction of rotation is cw, seen from the shaft end.



Connection

Water supply to the pump can follow either directly from the water supply or from a water tank, placed above the pump.

The pressure at the pump inlet must be max. 5 bar abs and min. 0,9 bar abs to prevent cavitation.

Filter

The pump must be supplied with a 10μ ($\beta_{10} = 75$) water filter.

In open-system applications (continuous supply of "new" water), the filter must be placed in the pump inlet.

In "hydraulic" applications, where the water is led back to a tank and recirculated, the filter should be placed on the return line of the system.

Please contact the Danfoss sales organisation for further filter details.

Code numbers

PAH 25	180B0006
PAH 32	180B0005
PAH 63	180B0004
PAH 80	180B0003

Appendix D: Sources Sought

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SYNOPSIS RESPONSE INFORMATION

SYNOPSIS NUMBER: N47408-94-R-9015

SUBJECT: SEAWATER HYDRAULIC MOTOR

Company Name: Allied Signal Inc.
Address: 1300 W Warner Road
Tempe AZ 22200
Company Size:
Telephone Number: 602-893-5000FAX Number: 602-893-5123
Point of Contact: James Hagerty

Company Name: Rotordynamics Seal Research
Address: 3628 Madison Avenue Suite 20
North Highlands CA 95660
Company Size:
Telephone Number: 916-344-9500FAX Number: 916-344-8400
Point of Contact: Joseph Scharrer

Company Name:
Address:

Company Size:
Telephone Number: FAX Number:
Point of Contact:

Company Name:
Address:

Company Size:
Telephone Number: FAX Number:
Point of Contact: .

Company Name:
Address:

Company Size:
Telephone Number: FAX Number:
Point of Contact: .

Company Name:
Address:

Company Size:
Telephone Number: FAX Number:
Point of Contact: .

Appendix E: Hydraulic Hose Comparisons

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SUPPLY/RETURN SIZE HYDRAULIC HOSE COMPARISON

HOSE DESCRIPTION	WORKING PRESSURE (psi)	BEND RADIUS (inches)	WEIGHT PER FOOT (lbs.)
Aeroquip FC701-16 (Thermoplastic)	2,500	12.0	0.36
Aeroquip FC701-20 (Thermoplastic)	2,500	12.0	0.58
Aeroquip GH781-16	2,500	6.0	0.72
Aeroquip GH793-16	2,500	12.0	1.01
Aeroquip FC195-16	2,500	12.0	1.04
Aeroquip 2781-16	2,500	12.0	1.06
Aeroquip 1508-20	2,500	16.5	2.01
Aeroquip GH493-24	2,500	20.0	2.10
Aeroquip FC250A-24	2,500	20.0	2.10
Aeroquip FC136-24	2,500	20.0	2.31
Aeroquip 2767-24	2,500	22.0	2.31
Aeroquip FC702-16 (Thermoplastic)	3,000	12.0	0.36
Aeroquip 1508-16	3,000	11.0	1.25
Aeroquip 2756-16	3,000	11.0	1.25
Aeroquip GH493-20	3,000	16.5	1.64
Aeroquip FC323-20	3,000	16.5	1.70
Aeroquip FC250A-20	3,000	16.5	1.84
Aeroquip FC254-24	3,000	20.0	2.11
Aeroquip 2767-20	3,000	18.0	2.13
Aeroquip FC136-20	3,000	16.5	2.13
Aeroquip FC323-24	3,000	20.0	2.20
Aeroquip FC324-16	***4,000***	***12.0***	***1.22***
Aeroquip GH493-16	4,000	12.0	1.22
Aeroquip FC136-16	4,000	12.0	1.35
Aeroquip FC262-16	4,000	14.0	1.35
Aeroquip FC250A-16	4,000	12.0	1.40
Aeroquip FC254-20	4,000	16.5	2.05
Furon Synflex 3350/3360-16 (Thermoplastic)	3,000	8.0	0.42
Parker 741-24	2,500	22.0	?
Parker 381-16	2,500	12.0	1.00
Parker 741-20	3,000	18.0	?
Parker 573X-16 (Thermoplastic)	3,000	10.0	0.41
Parker 573X-24 (Thermoplastic)	3,000	18.0	0.81
Parker 341-16	3,000	12.0	1.28
Parker 593-16 (Thermoplastic)	3,250	8.0	0.68
Parker 741-16	4,000	14.0	?
Imperial Eastman M724	2,500	20.0	1.99
Imperial Eastman L120	2,500	16.5	2.00
Imperial Eastman L220	2,500	16.5	2.05
Imperial Eastman L216	3,000	12.0	1.28
Imperial Eastman L116	3,000	12.0	1.28
Imperial Eastman M720	3,000	16.5	1.73
Imperial Eastman N316	3,500	13.0	1.20
Imperial Eastman M716	4,000	12.0	1.32

CASE DRAIN SIZE HYDRAULIC HOSE COMPARISON

HOSE DESCRIPTION	WORKING PRESSURE (psi)	BEND RADIUS (inches)	WEIGHT PER FOOT (lbs.)
Aeroquip FC390-08 (Thermoplastic)	2,500	3.5	0.16
Aeroquip FC690-08RL (Thermoplastic)	2,500	3.5	0.16
Aeroquip GH663-8	2,500	7.0	0.30
Aeroquip FC194-08	***2,500***	***7.0***	***0.38***
Aeroquip 2681-8	2,500	7.0	0.38
Aeroquip GH681-8	3,000	3.5	0.26
Aeroquip GH683-8	3,000	3.5	0.26
Aeroquip FC375-08 (Thermoplastic)	3,500	4.0	0.14
Aeroquip 374-08 (Thermoplastic)	3,500	4.0	0.14
Aeroquip FC310-08	3,500	5.0	0.34
Aeroquip FC510-08	3,500	5.0	0.34
Aeroquip FC474-08	3,500	7.0	0.42
Aeroquip FC212-08	3,500	7.0	0.48
Aeroquip 2766-8	3,500	7.0	0.54
Aeroquip 1546-8	3,500	7.0	0.64
Furon Synflex 3350/3360-08 (Thermoplastic)	3,000	3.5	0.19
Furon Synflex 3800-08 (Thermoplastic)	3,500	4.0	0.15
Furon Synflex 3R80-08 (Thermoplastic)	3,500	4.0	0.19
Furon Synflex 3580-08	3,500	3.3	0.21
Parker 53FR-8 (Thermoplastic)	2,500	3.0	0.18
Parker 560-8 (Thermoplastic)	2,500	3.3	0.20
Parker 580N-8 (Thermoplastic)	2,500	4.0	0.21
Parker 481-8	2,500	7.0	0.29
Parker 518C-8 (Thermoplastic)	3,000	3.0	0.15
Parker 53LT-8 (Thermoplastic)	3,000	3.5	0.19
Parker 520N-8 (Thermoplastic)	3,500	4.0	0.13
Parker 588N-8 (Thermoplastic)	3,500	4.0	0.21
Parker 590-8 (Thermoplastic)	3,500	3.3	0.25
Parker 301-8	3,500	7.0	0.45
Imperial Eastman HFS08	2,500	7.0	0.28
Imperial Eastman HR1C08	2,500	7.0	0.28
Imperial Eastman HR808/HR8008 (Thermoplastic)	3,500	7.0	0.17
Imperial Eastman NJ408	3,500	7.0	0.45
Imperial Eastman J408	3,500	7.0	0.45
Imperial Eastman J908	3,500	7.0	0.45
Imperial Eastman H108	3,500	7.0	0.57
Imperial Eastman H408	3,500	7.0	0.59